

**EFFECT OF CROP ESTABLISHMENT METHOD AND
DIFFERENT SOURCE OF ZINC ON GROWTH, YIELD
AND QUALITY OF RICE (*Oryza sativa* L.) cv PUSA-44**



ESTABLISHED BY PARLIAMENT BY NOTIFICATION NO. 225 OF 1916

THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
Master of Science (Agriculture)
in
Agronomy

Submitted by
Virendra Kumar Verma

Supervisor
Dr. R. N. Meena

Co-Supervisor
Prof. R. S. Singh

**DEPARTMENT OF AGRONOMY
INSTITUTE OF AGRICULTURAL SCIENCES
BANARAS HINDU UNIVERSITY
VARANASI-221005
INDIA**

I.D. No.A-12011

2014

Enrolment No.349622

VISIT...

LANZAROTE
Caliente.COM

VISIT...

LANZAROTE
Caliente.COM



*Affectionately Dedicated to
Maa Saraswati
&
My Venerated Parents
for their endless love, support and encouragement*

Virendra✍

Dr. R.N. Meena

Assistant Professor

☎ : 0542-26703509

Mob: 09451587255



Department of Agronomy
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi – 221005. U.P. India.

Ref. No.

Date: ... / ... / 2014

CERTIFICATE

To,

The Registrar (Academic)
Banaras Hindu University,
Varanasi-221005 (India).

Through: The Head, Department of Agronomy, Institute of Agricultural
Sciences, BHU, Varanasi-221005 (India)

Dear Sir,

I have great pleasure in forwarding the thesis entitled “**EFFECT OF CROP ESTABLISHMENT METHOD AND DIFFERENT SOURCE OF ZINC ON GROWTH, YIELD AND QUALITY OF RICE (*Oryza sativa* L.) cv PUSA-44**” submitted by **Mr. Virendra Kumar Verma, I.D. No. A-12011** in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture) in Agronomy**, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (U.P.) and placing on record that he has completed the requisite residential requirements as contained in the statutes of the university.

I certify that the entire scheme of investigation presented herein was planned and carried out solely by the candidate under my guidance and supervision. The data present in thesis, to the best of my knowledge and belief, are genuine and original.

Thanking you,

Yours Faithfully,

Forwarded by

(**R. N. Meena**)
Supervisor

**EFFECT OF CROP ESTABLISHMENT METHOD AND
DIFFERENT SOURCE OF ZINC ON GROWTH, YIELD
AND QUALITY OF RICE (*Oryza sativa* L.) cv PUSA-44**

by
Virendra Kumar Verma

Thesis submitted in the partial fulfilment of the
requirements for the degree of
MASTER OF SCIENCE (AGRICULTURE)
IN
AGRONOMY

**DEPARTMENT OF AGRONOMY
INSTITUTE OF AGRICULTURAL SCIENCES
BANARAS HINDU UNIVERSITY,
VARANASI – 221 005**

2014

ID. No.: A-12011

Enrolment No.: 349622

THESIS APPROVED BY ADVISORY COMMITTEE

- Chairman** : **Dr. R. N. Meena**
Assistant Professor
Department Agronomy,
Institute of Agricultural Sciences,
BHU, Varanasi, (U.P.), India.
- Co-Chairman** : **Prof. R. S. Singh**
Department of Agronomy,
Institute of Agricultural Sciences,
BHU, Varanasi, (U.P.), India.
- Member** : **Prof. Ram Kr. Singh**
Department of Agronomy
Institute of Agricultural Sciences,
BHU, Varanasi (U.P.), India.
- Member** : **Dr. P. K. Sharma**
Associate Professor
Department of Soil Science & Agricultural Chemistry
Institute of Agricultural Sciences,
BHU, Varanasi (U.P.), India.

EXTERNAL EXAMINER:

ACKNOWLEDGEMENT

With a deep sense of devotion I bow and pray to the feet of Lord Vishwanath and Sankat Mochan who provided me choicest, everlasting blessing to get an opportunity to study in Banaras Hindu University, the dream of Mahamana Pandit Madan Mohan Malviya ji, a great patriot, nobleman and patriarch of this university.

With immense pleasure and profound sense of gratitude, indeed, I take this opportunity to express my heartfull and sincere thanks to my esteemed supervisor, Dr. R. N. Meena, Assistant Professor, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, for his meticulous guidance, indelible inspiration, persistent encouragement, ingenious suggestions, mellifluous nature and indefatigable attitude. I will ever cherish the fatherly affection that he bestowed upon me throughout my tenure as a student under him which helped me to cope with many difficult situations.

I am highly obliged to Prof. Avijit Sen, Head Department of Agronomy for providing the necessary research and academic facilities during the course of investigation.

I owe my sincere thanks to the members of my advisory committee, Prof. R. K. Singh, Department of Agronomy and Prof. R. S. Singh., Department of Agronomy Dr. P. K. Sharma, Department of Soil Science and Agricultural Chemistry Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (U.P.) for their critical suggestion, impeccable and benevolent guidance.

I extend my indebtedness to the respected teachers of the Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University for their discerning comments, valuable suggestions, co-operations and helpful attitude towards me during the course of investigation.

My special thanks to Mr. Nandu Ram Yadav, Mr. Vijay Pratap Singh, Mr. J.C.N.Tripathi and Mr. Shyam Sundar for whole hearted co-operation and continues inspiration.

I owe my sincere thanks to all the staff members of Agricultural Research Farm and non-teaching staff of the Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University for their keen interest taken in the work providing the necessary and timely research facilities, inspiration and suggestion throughout the work,

With profound regards in a more personal sense, I owe deepest debts to my beloved parents Shri. Kalpoo Verma and Smt. Chandrawati Verma, my lovely brothers (Surendra, Satyabhan), my lovely sisters Shanti Verma, Pratibha Patel, Antima and my lovely nephew Satyam Patel, my cutie niece Saumya Patel and my lovely sister in law

Smt. Mithlesh Verma who taught me the value of wisdom based on erudition but without enslaved by it and their persistent inspiration, selfless sacrifice, continuous encouragement and blessing gave untiring help and have enabled me to be so today.

Words are not enough to express my deep sense of honour, unbounded gratitude and sincere regards to the **family members** and **Kanhaiya Lal Rajbhar** who set the foundation and were always with me during my ups and downs. I thank them once again because I would have never achieved this level of education without their selfless sacrifices.

Without the help of seniors no one can learn the lesson of life and cannot teach the same to loving juniors so, heartfelt and special thanks to my most hearty senior Mr. Lalji Yadav, Praveen Upadhyay, Saurabh Chaudhary, Kaushal Singh, Alok Pandey,, Santosh Patel, Amitesh Singh, Imtiyaz Ahmad, Umendra Singh, and Avinash Chandra Maurya for their co-operation during the study and investigation.

I am highly thankful to the company of my batchmates **P. N. S. Thakur, Ambuj, Gaurav, Ashwini, Pooja, Papia Biswas, Sanjeev Mishra, Jagdeesh Yadav** and **Jayant Shekhar** for their moral support, co-operation and priceless suggestions.

The words are inadequate to express my feelings to my friends **Arju, Mona, Pratima, Vishal, Rupesh, Umesh Singh Jat, Deepak Dixit, Vijay** and my lovely juniors **Shiv Bahadur, Geetanjali, Shivam, Sandeep, Lala Ram, Gangadhar Nanda, Mishan Das, Arditi and Kiran** for their immense love and affection which always animated me to face challenges.

Before pen down, I once again confess that I do not know how to acknowledge the help and co-operation of my Supervisor, members of advisory committee, family members and relatives, seniors, juniors, colleagues but above feelings are followed from the core of my heart in the shape of words and as gospel truth.

The graces of the God are always blessed to me and give me patience and power to overcome the difficulties which came my way in accomplishment of this endeavour. I cannot dare to say thanks but only pray to bless me always.

Last but not the least, I record my sincere thanks to all respectable people who helped me and could not find separated mention. I still solicit their benediction to proceed at every step of a perfect destined life.

Great thanks to all.

Date:

Place: Varanasi

(Virendra Kumar Verma)

CONTENTS

Chapter		Page No.
<i>Chapter I :</i>	Introduction	1-5
<i>Chapter II:</i>	Review of Literature	6-21
<i>Chapter III:</i>	Materials and Methods	22-42
<i>Chapter IV:</i>	Experimental Findings	43-61
<i>Chapter V:</i>	Discussion	62-69
<i>Chapter VI:</i>	Summary and Conclusion	70-73
	• Bibliography	i-xii
	• Appendices	

LIST OF SYMBOLS AND ABBREVIATIONS

%	Per cent
@	At the rate of
°C	Degree centigrade
m	Metre
cm	Centimetre
mm	Millimetre
t	Tonnes
q	Quintal
kg	Kilogram
g	Gram
ha	Hectare
m ha	Million hectare
<i>i.e.</i>	Id est (that is)
<i>et al.</i>	And others
<i>viz.</i>	Namely
e.g.	For example
d.f.	Degree of freedom
dSm ⁻¹	Decisiemen per metre
EC	Electrical conductivity
Fig.	Figure
NS	Non significant
DAS	Days after sowing
B : C	Benefit cost ratio
C.D.	Critical difference

Max.	Maximum
Min.	Minimum
No.	Number
pH	Power of Hydrogen Ion
SEm _±	Standard error of mean
/	per
hrs	Hours
₹	Rupees

LIST OF TABLES

TABLE NO.	DESCRIPTION	PAGE NO.
Table 3.1	Meteorological observations (standard week- wise) during the crop season 2013	23
Table 3.2:	Mechanical and physico-chemical analyses of soil of the experimental fields	26
Table 3.3	Cropping history of the experimental field	27
Table 3.4	Treatment detail.....	28
Table 3.5	Details of layout plan	29
Table 3.6	Treatment combinations (12) tested under experiment.....	29
Table 3.7	Details of field operations carried out during experiment.....	31-32
Table 3.8	Methods of plant chemical analysis	39
		AFTER PAGE NO.
Table 4.1	Effect of crop establishment method and different source of Zn on the plant height (cm) of rice	43
Table 4.2	Effect of crop establishment method and different source of Zn on the total number of tillers hill ⁻¹ of rice.....	44
Table 4.3	Effect of crop establishment method and different source of Zn on the number of total green leaves hill ⁻¹	44
Table 4.4	Effect of crop establishment method and different source of Zn on dry matter accumulation (g hill ⁻¹) of rice	45
Table 4.5	Effect of crop establishment method and different source of Zn on LAI of rice	45
Table 4.6	Effect of crop establishment method and different source of Zn on the chlorophyll.....	46
Table 4.7	Effect of crop establishment method and different source of Zn on yield attributing characters of rice	47

TABLE NO.	DESCRIPTION	AFTER PAGE NO.
Table 4. 8	Effect of crop establishment method and different source of Zn on yield attributing characters of rice.....	48
Table 4.9	Effect of crop establishment method and different source of Zn on grain yield (q ha^{-1}), straw yield (q ha^{-1}) and harvest index (%) of rice.....	50
Table 4.10	Effect of crop establishment method and different source of Zn on N concentration and N uptake (kg ha^{-1}) of rice.	51
Table 4.11	Effect of crop establishment method and different source of Zn on P concentration (%) and P uptake (kg ha^{-1}) of rice	53
Table 4.12	Effect of crop establishment method and different source of Zn on K concentration (%) and K uptake (kg ha^{-1}) of rice	54
Table 4.13	Effect of crop establishment method and different source of Zn on the Zn concentration (mg kg^{-1}) and Zn uptake (g ha^{-1}) of rice	56
Table 4.14	Interaction effect between crop establishment method and different source of Zinc on Zinc uptake (g ha^{-1}) in grain of rice	57
Table 4.15	Effect of crop establishment method and different source of Zn on the Protein content (%) and uptake (kg ha^{-1}) of rice	58
Table 4.16	Effect of crop establishment method and different source of Zn on different quality parameter of rice.....	59
Table 4.17	Economics of treatment combinations	61

LIST OF FIGURES

FIGURE NO.	DESCRIPTION	PAGE NO.
Figure 3.1	Meteorological observations (Standard week wise) obtained from the Meteorological observatory of the, Banaras Hindu University, during experimental period (2013-14).....	24
		AFTER PAGE NO.
Figure 3.2	Layout Plan (Split Plot Design).....	29
Figure 4.1	Effect of crop establishment method and different source of Zn on the plant height (cm) of rice	43
Figure 4.2	Effect of crop establishment method and different source of Zn on the total number of tillers hill ⁻¹ of rice.....	44
Figure 4.3	Effect of crop establishment method and different source of Zn on dry matter accumulation hill ⁻¹ of rice	45
Figure 4.4	Effect of crop establishment method and different source of Zn on LAI of rice	45
Figure 4.5	Effect of crop establishment method and different source of Zn on yield attributing characters of rice.....	47
Figure 4.6	Effect of crop establishment method and different source of Zn on yield attributing characters of rice.....	48
Figure 4.7	Effect of crop establishment method and different source of Zn on grain yield (q ha ⁻¹) , straw yield (q ha ⁻¹) and harvest index (%) of rice.....	49
Figure 4.8	Effect of crop establishment method and different source of Zn on total uptake of NPK (kg ha ⁻¹) of rice.....	51
Figure 4.9	Effect of crop establishment method and different source of Zn on Zn content (mg kg ⁻¹) and total Zn uptake (g ha ⁻¹) of rice.....	56
Figure 4.10	Effect of crop establishment method and different source of Zn on different quality parameter of rice.....	59

CONTENTS

Chapter	Particular	Page(s)
<i>Chapter I :</i>	Introduction	1-5
<i>Chapter II:</i>	Review of Literature	6-21
<i>Chapter III:</i>	Materials and Methods	22-42
<i>Chapter IV:</i>	Experimental Findings	43-61
<i>Chapter V:</i>	Discussion	62-69
<i>Chapter VI:</i>	Summary and Conclusion	70-73
	References	i-xii

INTRODUCTION

Rice (*Oryza sativa*, L) is a staple food for more than 70 per cent of the people living in the Asia continent where more than 90 per cent of rice produced and consumed. It is extensively grown in tropical and sub-tropical regions of the world. It is grown in 112 countries in the world, covering every continent and is consumed by 2500 million people in developing countries (Datta and Khush, 2002).

FAO estimated that rice crop consumes about 4000-5000 litres of water for production of per kg grains and thus consuming more than 50% of water use in Agriculture. Increasing water scarcity is making it difficult to sustain the area currently under irrigated rice. In India rice is presently grown in an area of 44.5 M-ha with the production of 96.0 Mt which is about 20% of world total food production (Anonymous, 2012). The per hectare yield of rice (2.56 t ha^{-1}), in India through increasing marginally but is still well below the worlds average yield of 4.0 t ha^{-1} (FAO, 2006).

In Indo-gangetic plains, including Varanasi region, rice is almost entirely planted by manual transplanting on puddled bed. Puddling of the soil reduce percolation losses of water, control weed and create favourable condition for rice establishment as well as growth and development besides having better water management. Nevertheless, this has adverse effect on soil physical properties and creates less favourable effect for following crop. In this context, to solve the problem of labour shortage, alternate methods of rice stand establishment are inevitable. It is an effort to achieve the sustainability and stability in rice production systems.

In many regions farmers fail to undertake timely transplanting which results in reduction of rice yield. Conventional rice transplanting methods require high labour, high production cost, high water use, drudgery to farm work. The alternative to this could be different method of rice establishment which would allow 10-15 days earlier

transplanting than conventional method thereby allowing timely planting of succeeding wheat crop (Uphoff, 2005).

System of Rice Intensification (SRI) is another alternative practice to solve the water crisis and as a methodology for increasing the productivity of irrigated rice by changing the management of plant, soil, water and nutrients (Natarajan, *et. al.*, 2008). The rice yield could be tripled by adopting SRI method compared to traditional method of cultivation mainly due to planting of seeding before third phyllochron leads to higher productive tillers and yield (Andrainaivo, 2002).

SRI was developed in 1980 by Henri de Laulanie, a French Jesuit working with Madagascar farmers and formed a NGO “Association Tefy Saina”, who spent more than three decades in Madagascar trying to devise better production methods that would improve the lives of rural household, who were impoverished and heavily dependent on rice (Laulanie, 1993).

Farmer’s practice is a traditional rice cultivation system, common throughout the rainfed regions of eastern India. This method facilitates stable rice yields under low levels of inputs and uncertain climatic conditions through effective weed control, stimulated root growth and optimum plant stand with enhanced tillering.

Zinc is one of the 17 essential elements necessary for the normal growth and development of plants. It is among eight micronutrients essential for plants. Zinc plays a key role in plants with enzymes and proteins involved in carbohydrate metabolism, protein synthesis, gene expression, auxin (growth regulator) metabolism, pollen formation, maintenance of biological membranes, protection against photo-oxidative damage and heat stress, and resistance to infection by certain pathogens (Alloway 2008).

Raising the micronutrient content in grain is a effective approach towards nutritional security. Food biofortification either by plant breeding (genetic biofortification) or by the use of micronutrient fertilizers (agronomic biofortification) can both contribute to this goal. It is important to note that biofortification for health

purposes require higher levels of micronutrients in grain than is necessary to achieve optimum crop yields (IFA, 2004).

Zinc is essential for all humans, animals (Broadley, *et. al.* 2007) and plants (Prasad 2008). It is vital for the proper functioning of the immune system and crucial for healthy growth, physical and mental development of children.

As Zn plays multiple roles in plant biochemical and physiological processes, even slight deficiency causes a decrease in growth, yield, and Zn content of edible plant parts. Zn deficiency is a serious agricultural problem as around one half of the cereal-growing soils in the world contain low Zn in the soil (Graham and Welch 1996; Cakmak *et al.* 1999). The solubility and availability of Zn is determined by various factors like high CaCO₃, high pH, high clay soils, low organic matter, low soil moisture, and high iron and aluminum oxides (Cakmak 2008).

Zn content in food is very important for human health as the artificial supplementation of food with essential minerals is often difficult to achieve, particularly in developing countries. Therefore, it has been suggested that increased levels of Zn in staple food, e.g., rice may play a role in reducing Zn deficiency (Ruel and Bouis 1998; Graham *et al.* 1999; Welch and Graham 1999).

Zn deficiency causes decrease in plant growth and yield. In addition, Zn is critical to the control of gene transcription and the coordination of other biological processes regulated by proteins containing DNA-binding Zn-finger motifs (Rhodes and Klug 1993).

In India 26% population are suffering from zinc deficiency. The children are the most affected part of this 26% population and about 54% children suffering from zinc deficiency (ICMR 2012).

Effective zinc nutrition one person require 15 mg Zn/day (NRC,1989) but our food grains contain only 15-35 mg Zn/kg (Cakmak, *et.al.* 2004) and out of which only 13-35% are bio available (Halberg and Halthen, 2000). So there is a big gap between daily requirement- daily intake and to fulfil the gap our food grains should contain 40-60 mg Zn/kg (Pfeiffer and Clafferty, 2007).

Biofortification focuses on enhancing the zinc nutritional qualities of crops at source, which encompasses process that increase both Zn levels and their bioavailability in the edible part of the staple crops. Biofortification is of two types agronomic and genetic biofortification. Agronomic approaches for zinc enrichment in food grains adequate zinc fertilization, type, time and method of zinc application. With the increase in the level of zinc fertilizers the zinc concentration in grains of aromatic rice also increases (Shivay, *et. al.* 2010) and zinc sulphate enriched urea is better in enriching the zinc in rice grains than the zinc oxide enriched urea (Prasad, *et. al.* 2013).

Combined application of zinc fertilizers and organic matter (FYM) or in corporation of green manure resulted in significant increment in zinc concentration in food grains than zinc fertilizers alone (Ahmad, *et.al.*2012, Singh, *et.al.* 2013 and Pooniya, *et.al.* 2013). Combined application of zinc treated seeds, soil and foliar zinc application contribute more zinc to grain than untreated seeds (Hussain, *et. al.* 2012)

Zinc deficiency leads to the hidden hunger or malnutrition. Experts estimate that 2 billion peoples, mostly in poorer countries are suffering from the micronutrient malnutrition (Bouis *et. al.* 2011)

Zinc is now recognized as the fifth leading risk factor in developing Asian countries (IFA, 2007) and efforts are underway for encouraging Zn fertilization not only from the view point of getting higher yields and quality produce, but also for increasing Zn concentration in grain and straw to improve human and animal Zn nutrition (Schardt, 2006).

Keeping pace with these facts in view, the present investigation entitled **“effect of crop establishment method and different source of zinc on growth, yield and quality of rice (*Oryza sativa* L.) cv PUSA-44”** was undertaken at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, during the *kharif* season of 2012-13 with the following objectives:

1. To study the effect of crop establishment method and different source of zinc on growth, yield and quality of rice.
2. To find out the most appropriate crop establishment method and the use of different source of zinc application on transplanted rice.
3. To workout economics of different treatments.



REVIEW OF LITERATURE

Rice is the most important cereal crop of India. It is globally cultivated under varied agro-climatic conditions. Consequently it is faced with limitations of various kinds. However, the rice is subjected to face more challenges as it is grown in a more riskful environment, notably, nutritional disorders, moisture stress, infestation by insect-pest and diseases along with weeds etc., which are responsible for its poor growth, development and consequently low yield. Exploitation of the genetic yield potential of any crop depends entirely on appropriate crop management practices, particularly better crop establishment, adequate supply of water and mineral nutrition along with effective plant protection measures. In recent years intensive cultivation of high yielding varieties of rice with excessive use of macro nutrients (NPK) fertilizers have accelerated the depletion of certain secondary and micro nutrients from the soil leading to emergence of their deficiencies in many parts of country.

It is the most important crop in India and is also the hub of food security of the global population. Among different production factors, planting methods produce significant effects not only on paddy yield and grain quality of rice but also on soil health and productivity.

To meet the challenges of food security for rapidly increasing population, intensive cropping pattern were adopted which resulted in declining nutrient status of soil and therefore the use of chemical fertilizer are increasing day by day. Micronutrient deficiencies affecting crop yields are difficult to be corrected due to large temporal and special variation in availability, quick conversion and fixation in to unavailable form and poor movement of applied micronutrients in soil profile. Soil applied micronutrients are not readily transported to the shoot; similarly foliar applied micronutrients are also inefficiently transported to roots. Therefore, application of micronutrients applied either in soils or on foliage may be successful in enhancing grain yield only under well-defined agroecosystem. Hence extrapolating results to a

new situation is unlikely to be successful without a specific adjustment in the fertilizer schedule. A brief review of literature pertaining to the present investigation entitled “**Effect of crop establishment method and different source of Zinc on growth yield and quality of rice (*Oryza sativa* L.)**” has been presented in this chapter under different sub-headings:

2.1 Growth, yield and yield attributes parameter

Tripathi *et al.* (1999) found that the maximum grain yield was recorded by transplanting rice, significantly higher than dry seeding in both the season and broadcast in 1994-95. Over the years, the higher rice yield in transplanted condition was mainly attributed to increase in panicle/m², grains /panicle and 1000 grain weight. Similar results were also reported by Dhiman and Sharma (1986).

Singh (2001) reported that puddling increased grain yield and straw yield of rice by 0.7 – 1.0 tonnes ha⁻¹ and 0.8 - 1.7 tonnes per ha⁻¹ respectively.

Singh *et al.* (2005) reported that mechanical transplanting of rice resulted in 6.25 tonnes/ha grain and 6.94 tonnes /ha straw yield that remained at par with manual transplanting but significantly higher than direct seedling methods.

Saha *et al.* (2010) conducted a trial and found that among different crop establishment method, SRI (System of Rice Intensification) showed maximum plant height (82.5 cm), dry matter production (558 g m⁻²), number of tillers (312.37) and yield attribute viz., effective panicles m⁻² (306.5), panicle weight (5.40 g) and test weight (23.92 g) and grain (5.47 tha⁻¹) and straw yield (7.66 tha⁻¹) as compared to drum seeder, line sowing and broadcasting methods, respectively. The percentage increase in yield of SRI over transplanting method of SRI was found to be 5.20%. However, SRI showed values for growth parameters, yield attributes and yield at par with ICM (integrated crop management) and transplanting methods. Also, SRI showed maximum water use efficiency (36.98 kgha⁻¹cm) and highest benefit: cost ratio (3.12).

Sridevi *et al.* (2012) observed that SRI planting (25cm×25cm) and weeding with two way rotary weeder thrice at weekly interval starting from 15 DAT along with recommended dose of fertilizer (150:50:50 kg NPK ha⁻¹) +12.5 tonnes ha⁻¹ FYM + Azophosmet (seed and soil application) + PPFM (foliar spray) at active tillering, panicle initiation and 50 per cent flowering stage registered higher grain yield and net return.

Jagtap *et al.* (2012) conducted the experiments laid out in split plot design replicate thrice with five crop establishment method in the main plot and three fertilizer sources were assigned in the sub plots. The results revealed that transplanting of rice recorded significantly higher grain yield (50.21, 54.95 and 52.58 qha⁻¹), straw yield (59.89, 64.07 and 61.98 qha⁻¹).

2.2 Nutrient uptake parameter

Parihar (2004) reported that puddling and transplanting of rice seedling gave higher yield and nutrient uptake than other methods of rice establishment combination.

Soil chemical analysis showed that available soil N, P and K contents were affected significantly due to seeding methods and tillage, significantly greater available soil N, P and K were recorded under direct seeding of rice followed by manual and mechanical transplanting. Conventional tillage recorded significantly lower available soil N and higher value of soil P & K, whereas zero tillage recorded higher value of available soil N and lower value of available soil P and K during the 3 years of study (Gangwar *et al.*, 2004).

Mankotia *et al.* (2006) an experiments were conducted during the 2004 and 2005 *kharif* seasons in Himachal Pradesh, India, to evaluate the system of rice intensification (SRI) and integrated crop management (ICM) methods of rice establishment compared to conventional transplanting (CT) method. CT gave the maximum plant height, mean number of tillers and mean grain yield.

Ali *et al.* (2007) reported that crop establishment method did not significantly influence uptake of indigenous mineral N during the wet (44-55 kg ha⁻¹) and dry (43-

50 kg ha⁻¹) seasons. Apparently, NH₄⁺ N and NO₃⁻ N accumulated in the top 20-cm layer of the soil during the wet season, resulting in relatively high initial N during the dry season. Crop establishment and N management strategies did not influence crop removal of N during a one-year period.

Jaydev *et al.* (2010) showed pooled data of two seasons indicated that total volatilization and leaching losses were significantly lower in aerobic technique (2.74 and 3.60 kg N ha⁻¹, respectively) compared to transplanting and system of rice intensification technique. Among the sources of N, application of large-sized urea granules recorded significantly lower total volatilization and leaching losses (3.75 and 4.80 kg N ha⁻¹, respectively).

2.3 Economics parameter

Sharma *et al.* (2006) reported that manual transplanting was more energy efficient, requiring lowest specific energy (444 Kcal/kg) and providing maximum energy use efficiency (6.75) whereas direct seeding of sprouted rice was most cost effective, requiring low specific cost (Rs2.42/kg) with maximum benefit: cost ratio (2.39).

Sridevi *et al.* (2012) found that B:C ratio was higher with SRI planting and weeding with two way rotary weeder thrice at weekly interval starting from 15 DAT and application of recommended dose of fertilizer (150:50:50 kg NPK ha⁻¹).

Jagtap *et al.* (2012) found and revealed result that transplanting of rice recorded significantly gross returns (Rs. 60447.5, 65847.1 and 63147.33 ha⁻¹), net returns (Rs. 20547.5, 17457.8 and 19002.72 ha⁻¹) and benefit to cost ratio (1.52, 1.36 and 1.44) during year 2009, 2010 and pooled mean, respectively compared to rest of the crop establishment method.

2.4 Effect of different source of zinc on plant growth, yield attributes, yield, quality, nutrient content of rice and its removal.

Zinc is the most important trace element. Rice which is absorbed by rice in enough quantity to complete its life cycle (Sommer and Lipman, 1926 and Arnon and

Stout, 1939). The role of zinc has long been recognized to have a stimulating effect on rice causing significant increase in the number of productive tillers, dry matter production and leaf area index with every increase in the levels of zinc sulphate. Grewal *et al.* (1997) observed that increase in the level of zinc sulphate significantly increased the plant growth parameters such as dry matter, leaf area index and crop growth rate.

Zinc deficient soil and zinc deficiency in rice is reported worldwide (Alloway, 2004; Cakmak, 2009; Fageria *et al.*, 2002; Gao *et al.*, 2006; Norman *et al.*, 2003; Silanpaa, 1990; Yoshida *et al.*, 1973). Zinc deficiency in rice was first reported by Nene (1966) from GB Pant University of Agriculture and Technology, India and is characterized by the appearance of dark brown spots on the leaves, which in severe deficiency may coalesce to give dark brown colour to the entire plant. This deficiency was given the name *kharia* disease due to the brown colour of the extract of *Acacia catechu*. In India, about 49 % soils are deficient in Zn (Behera *et al.*, 2009a, b).

Zinc deficiency causes a decrease in plant growth and yield (Ishimaru *et al.*, 2011). As Zn plays multiple roles in plant biochemical and physiological processes, even slight deficiency causes a decrease in growth, yield, and Zn content of edible plant parts. Zn deficiency is a serious agricultural problem as around one half of the cereal-growing soils in the world contains low Zn in the soil (Graham and Welch, 1996; Cakmak *et al.*, 1999). The solubility and availability of Zn is determined by various factors like high CaCO_3 , high pH, high clay soils, low organic matter, low soil moisture, and high iron and aluminum oxides (Cakmak, 2008).

Jat *et al.* (2011) reported that the highest agronomic efficiency (AE) was obtained with the application of 2% Zn-enriched urea ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$). Physiological efficiency (PE) and Zn harvest index (ZnHI) of applied Zn were also significantly influenced due to dual purpose summer legumes and applied in aromatic hybrid rice. Treatments (10) FYM + ESR + 33% extra fertilizers (EF) + FSS. (9) FYM + RSR + RF + FSS; and (8) FYM + recommended seed rate (RSR) + adjusted fertilizers + ferrous sulfate spray (FSS) recorded the highest values for leaf area, dry matter accumulation, plant height, number of functional leaves, number of grains per

panicle. The 3 highest grain (1273, 1230 and 1212 kg ha⁻¹) and straw (2049, 1979 and 1939 kg ha⁻¹) yields were also obtained from the above mentioned (Asewar *et al.* 2000).

Ismail (2000) reported that zinc deficiency is one of the most wide spread micronutrient deficiencies in plant causing severe reduction in crop productivity. There are a number of physiological impairments in Zn deficient cells causing inhibition of growth, differentiation and development of plants. Increasing evidence indicates that oxidative damage to critical cell compounds resulting from attack by reactive O₂ species of (ROS) is the basis of disturbances in plant growth caused by Zn deficiency. Zn interferes with membrane bound NADPH oxides producing ROS. In zinc deficient plant the Fe concentration increases and potentiates the production of free radicals. The zinc nutritional status of plants influences photo-oxidative damage to chloroplast, catalyzed by ROS. Zn deficient leaves are highly light sensitive, rapidly becoming chlorotic and necrotic when exposed to high light intensity. Zn plays critical roles in the defence system of cell against ROS and thus represents an excellent protective agent against the oxidation of several vital cell components such as membrane lipids and proteins, chlorophyll SH- containing enzymes and DNA. The cysteine, histidine and glutamate or aspartate residues represent the most critical Zn - binding sites in enzymes, DNA- binding proteins (Zn- finger proteins) and membrane proteins. Physiological process are impaired in plant suffering from Zn deficiency, it causes rapid inhibition of plant growth and development and thus the final yield.

Zinc application irrespective of methods of its application (Yilmez *et al.*, 1997) significantly increased grain yield. This was attributed to dilution of Zn in plant tissue because of enhanced dry matter production (Rengel and Graham, 1995). Zinc application @ 25-30 kg ha⁻¹ was sufficient to correct Zn deficiency for 4-7 years and the residual effect was best with soil application on long range basis. It has also been observed that after a certain limit in micronutrient fertilization further increase in fertilizer application caused not only reduction in yield but also decreased micronutrient grain density as reported by Nambiar and Motiramani (1983). Prashad *et al.* (1995) reported that rice transplanted with 10t ha⁻¹ compost and 100 kg N + 80

kg P₂O₅ + 40 kg K₂O and 0.0, 1.25 or 2.6 ppm Zn produced higher grain yield of 4.37, 4.37, 4.00 and 4.07 t ha⁻¹ with NPK and compost as compared to control (2.48 t ha⁻¹) and NPK alone (3.65 t ha⁻¹).

Zinc nutrition is known to increase tillering in rice, which might have caused a significant increase in dry matter production (Ghatak *et al.*, 2005). Slaton *et al.* (2005) have also observed an increase in dry matter accumulation of rice by application of Zn. Application of Zn, from Zn-coated urea and other sources is reported to have beneficial effect on LAI (Grewal *et al.*, 1997).

Giordano *et al.* (1974) studied the absorption of zinc by 14 day old intact rice seedling in short term uptake experiments in solution culture. They suggested that high solution concentrations of reduced iron and manganese which is developed in paddy culture may be related to zinc nutrition of rice. Prasad (2006) reported that critical values of DTPA extractable Zinc varied from 0.38-1.34 mg kg⁻¹ (with a general value 0.6) depending upon soil and crop. The lower critical limit of Zinc in plant tissue is generally accepted as 20 mg kg⁻¹ dry matter.

2.5 Effect of different source of zinc on yield attributes of rice

Karak *et al.* (2006) revealed that the use of different sources of Zinc (Zn-EDTA, and ZnSO₄·7H₂O) gave significantly increase both rice grain (4.56 tonnes ha⁻¹) and straw (6.88 tonnes ha⁻¹) yield during two year experiment where 1.0 kg Zinc applied as Zn-EDTA.

Dravid and Goswami (1987) reported significant increase in the number of panicles per square metre, more number of grains per panicle and increased panicle weight with the increase in the levels of zinc sulphate. These results were further confirmed by Ahmad *et al.* (1992); Mali and Sheikh (1994); Devarajan and Krishnasamy (1996). However, contrary to this Agarwal *et al.* (1997) found no significant difference in panicle length and fertility percentage of rice due to the application of Zn.

Yao-Zheng *et al.* (1998) and Kumar *et al.* (1999) reported that zinc sulphate level could not influence panicle weight, fertility percentage and test weight of rice. However, Rengel and Graham (1995) reported an appreciable improvement in the rice yield attributes like panicle length, fertility percentage and test weight due to increase in the levels of zinc sulphate. Application of GM with *Azospirillum* recorded significantly shorter period for 50 per cent flowering, highest number of productive tillers m⁻², filled grains per panicle, panicle length and grain yield (5282 and 5218 kg ha⁻¹). The highest level of N (187.5 kg ha⁻¹) with Zn application recorded significantly higher yield attributes and yield (5516 and 5376 kg ha⁻¹) than 150 kg N ha⁻¹ with Zn (Shanmugam and Veeraputhran, 2001).

A significant increase in yield and yield components was recorded for increasing levels of Zn. The application of 1.0% Zn solution appeared to be an optimum level for rice crops in these soil series. Tikken soil series gave the highest paddy and straw yields, while the Ramak series gave the lowest. The interaction between the soil series and Zn levels was significant for all parameters (Khan *et al.* 2005). Tripathi and Tripathi (2004) found that application of 30 kg ZnSO₄ ha⁻¹ resulted in significantly higher grain and straw yields, harvest index, seed weight per panicle and 1000-seed weight. The levels and mode of application of zinc and iron considerably increased the growth, yield attributes and yield of rice-wheat cropping system and also improved the soil contents of these micronutrients. Application of 30 kg ZnSO₄ + 5 kg FeSO₄ ha⁻¹ through chelating with FYM was found to be the best combination for rice (Kulandaival *et al.* 2004).

Application of ZnSO₄ with pressmud exhibited 46.1% higher yield over the untreated control and 26.9% increased yield than ZnSO₄ without organic enrichment. ZnSO₄ with pressmud produced the highest mean yield of 36.46 quintal ha⁻¹ (Mani *et al.*, 2001).

Biswas and Dravid, (2001) recommended application of 25 kg ZnSO₄ ha⁻¹ at puddling under normal soil condition mixed with equal amount of dry soil. Supplementing Zn with 0.52 mol Zn litre⁻¹ resulted in the largest root shoot ratio and

highest yield of biomass and rice grain (Lizhi *et al.*, 2003). Significant increase in yield and Zn uptake were recorded due to application of 30 kg ha⁻¹ (Rao, 2003).

Patil and Meisheri (2003) studied the direct and residual effect of applied Zn in rice-rice cropping system and reported that direct effect of 25 kg ZnSO₄ ha⁻¹ or 10 kg Zn chelated ha⁻¹ though were at par but significantly increased paddy yield over N, P, K. However, when combined with 10 t FYM ha⁻¹ it produced significantly higher yield over other treatments. Uptake of Zn in straw, grain as well as its residual content also increased due to applied Zn along with FYM. Similarly application of zinc with or without FYM brought about significant increase in grain and straw yield of subsequent rice crop.

Suri and Kumar (2006) reported equal affectivity of zincated urea with ZnSO₄. Application of 0.5 kg Zn ha⁻¹ as Zn-EDTA, and 1.0 kg ha⁻¹ as Zn-EDTA in 2 equal split revealed that split application of chelated zinc proved much effective and produced highest rice yield of 4.56 t ha⁻¹ (Karak *et al.*, 2005). Rahman *et al.* (2007) reported a positive correlation with dry matter yield and plant Zn content of rice in calcareous soils.

Alamdari *et al.* (2007) observed maximum Zn content in the leaves due to NPK, S and ZnSO₄ application which proved superior to the control. However, Zn and Cu contents in the grain markedly increased when NPK, S and Zn, Cu and MnSO₄ were applied together.

Pandey *et al.* (2007) and Mandal *et al.* (2009) reported that the application of FYM at the rate of N₁₅₀, P₇₅, K₆₀ OR N₁₀₀, P₆₀, K₄₀ or organic fertilizer level of N₁₀₀, P₆₀, K₄₀+Zn remained at par but produced significantly higher panicle⁻² and test weight over control. Similarly treatment N₁₅₀, P₇₅, K₄₆+FYM and N₁₀₀, P₆₀, K₄₀+FYM significantly increased the yield and nutrient uptake. It could be due to slow release of nutrients for longer period after decomposition of FYM, which favoured better plant growth and improved the yield component of hybrid rice, (2004).

Shivay *et al.* (2008) observed increased uptake of zinc due to zinc enriched urea (ZEU). Field experiment were conducted for two consecutive years at research farm of Indian Agricultural Research Institute, New Delhi India during rainy (Rice) and winter (Wheat) seasons of 2004-2006 on sandy loam soil. While studying the response of prilled urea (PU) and zinc-enriched urea results revealed that the Zn enriched urea (ZEU) produced significant in growth, yield attributes and yields of aromatic rice. Highest values for all these attributes and yields were recorded with highest enriched (3.5%) of the P.U. with zinc. However 1% ZEU proved the most economic source for aromatic rice and wheat cropping system and recommended for rice-wheat cropping system.

Naik and Das (2008) examined the relative performance of chelated Zn-EDTA and ZnSO₄. Initial incorporation of chelated zinc showed pronounced effect on growth over single basal application of ZnSO₄. The highest rice grain and straw yield were recorded due to application of 1 kg Zn ha⁻¹ as Zn-EDTA as basal with highest mean filled grain percentage, thousands grain weight and number of panicle/ m².

Varshney *et al.* (2008) observed that application of 10 kg ZnSO₄ to rice in the first year followed by 5 kg Zn ha⁻¹ in second year under hybrid rice wheat sequence in Tarai region, significantly increased the grain yield of both crops along with increased Zn uptake. Hybrid rice showed marked efficiency in uptake of Zn over wheat.

Mandal *et al.* (2009) observed the effect of ZN in combination with FYM and recommended their application to transplanted rice. Application of 10 kg Zn in three splits combined with RD of NPK recorded significantly higher growth, yield attributes, grain and straw yield and showed additional net return.

Jana *et al.* (2009) conducted a field experiment to study the effect of zinc application on transplanted rice grown on farmers field in red and laterite soil and reported that zinc application produced significantly greater yield attributes, higher grain and straw yields of rice. Application of 30 to 40 kg ZnSO₄ ha⁻¹ gave significantly higher value of plant height, number of effective tillers, panicle length,

grain number per panicle, grain and straw yields and higher uptake of NPK and Zn in grain and straw of rice. Also 30 to 40 kg ZnSO₄ gave greater yield response and higher net return.

Sridevi *et al.* (2010) reported positive effect of zinc-enriched organic manures. The results of the field experiment revealed that recommended dose of NPK+200 kg FYM enriched with 5.0 kg zinc increased the grain and straw yields due to increased availability of zinc. Uptake of nitrogen, phosphorous and potassium, and zinc also showed uniform increased in uptake.

Chandrapala *et al.* (2010) observed that application of S, Zn and FYM significantly improved the productivity of rice and succeeding maize crop. Among nutrient management practices, NPK + Zn + S recorded higher grain yield and yields attributes of rice cultivation. NPK+FYM application to rice crop recorded significantly highest quantity of available soil N, P and K content after crop harvest.

Kumar and Kumar (2010) reported on effects of rates and methods of zinc fertilizers applications in rice under flood prone conditions. There was a significant increase in yield and yield attributes of rice upto 45 kg ZnSO₄ ha⁻¹. The content and uptake of zinc also increased significantly with increasing levels of zinc sulphate. Soil applied Zn proved superior as compared to its foliar application.

2.6 Effect of different source of zinc on yield of rice

Singh *et al.* (1987) advocated that rice grain and straw yields increased progressively with the increase in the level from 10 to 30 kg ZnSO₄ ha⁻¹. The linear and significant response of rice grain and straw yield up to 40 kg ZnSO₄ ha⁻¹ was also observed by Saraswat and Bansal (1991) and Singh *et al.* (1992). The results were confirmed further by Zhang and Barrow (1993), Prasad and Umar (1993); Singh *et al.* (1996) and Grewal *et al.* (1997). Thus it is well established that application of zinc sulphate had significant influence on rice plant growth characters, yield attributing parameters and grain and straw yields. However, the degree of influence varied depending upon the soil type, weather condition, duration of the crop, method of rice culture and mode of application of zinc sulphate.

The frequency of zinc application, based on 10 cropping systems, indicates that the use of 25 kg zinc sulfate/ha as soil application after a two crop interval was optimal. The rate of increase in yields of rice and wheat was 52.4 and 21.0 kg per kg of zinc sulfate, respectively, and the percent increase in yield of rice was 46.6 and in wheat 38.1. The rice and wheat yield in the cropping system was significantly correlated with zinc removal (Prasad *et al.* 2002). Kumar (1999) obtained best results with application of 25 kg ZnSO₄ to transplanted plants, spraying with 0.5% ZnSO₄ solution 3 weeks after transplanting or dipping seedling roots in 2% ZnO suspension. Zn application in the nursery was effective in correcting Zn deficiency and improving yield even when zinc was not applied after transplanting.

2.7 Effect of different source of zinc on quality of rice

In addition, Zn is critical to the control of gene transcription and the coordination of other biological processes regulated by proteins containing DNA-binding Zn-finger motifs (Rhodes and Klug 1993). Food Zn content is very important for human health as the artificial supplementation of foods with essential minerals is often difficult to achieve, particularly in developing countries. Therefore, it has been suggested that increased levels of Zn in staple foods, e.g., rice may play a role in reducing Zn deficiency (Ruel and Bouis, 1998; Graham *et al.*, 1999; Welch and Graham, 1999).

Zn deficiency is a serious nutritional problem, affecting an estimated one third of the world's population (Sandstead, 1991) and contributing to 0.8 million deaths per year. Jat *et al.* (2011) observed that cooking quality parameters could be significantly improved by legume residue incorporation along with application of Zn-enriched urea. The N and Zn fertilization is directly responsible for higher 1,000-grain weight because N increased the crude protein content in grains (Naik and Das, 2008).

Singh *et al.* (2005) investigated the response of varying rates and mode of N and Zn application on rice and concluded that the highest amount of Zn acquisition in grain and straw was recorded due to 3 split application of N (135.55 g ha⁻¹) with two foliar spray and root dipping in Zn solution (127.15g ha⁻¹) in calcareous soil, Rahman *et al.* (2007) reported a positive correlation with dry matter yield and plant zinc content.

Mollah *et al.* (2009) failed to observe any marked variation in yield of rice due to different brands of Zn fertilizers. However the nutrient content in grain and straw significantly increased.

2.8 Effect of different source of zinc on content and uptake by rice

Ugurluoglu and Kacar (1996) reported that different sources of Zinc ZnO, ZnSO₄.7H₂O & Zn-EDTA on rice he found that application of Zinc @ 8 mg kg⁻¹ as Zn-EDTA was found most effective in the enhancement of Zn content in rice plant.

The uptake of nutrient by a crop depends upon the total biomass production and nutrient concentration in plant parts which in turn is influenced by soil climate, cultural practices, levels of nutrients applied and age of the plant (Gupta and O'Toole, 1986). Favourable increase in zinc uptake due to increased supply of zinc has been reported by Gurmani *et al.* (1988); Chhibba *et al.* (1989); Deb (1989) and Sachdev and Deb (1990). From their studies Indulkar and Malewar (1991), Singh *et al.* (1992) and Kumar *et al.* (1999) noticed a significant increase in zinc uptake with every increase in the levels of zinc sulphate application. Rice genotypes differ greatly in Zn use efficiency and grain Zn contents and this aspect has been investigated by various researchers (Graham *et al.* 1999; Nagarathna *et al.* 2010; Neue, *et al.* 1998; Refuerzo *et al.* 2009; Wissuwa *et al.* 2006; Wissuwa *et al.* 2008; Yang *et al.* 1998). Rice grain Zn concentrations ranged from 15.9 to 58.4 mg kg⁻¹ (Graham *et al.* 1999). Depending on soil Zn status, grain Zn concentrations could range from 8 to 47 mg kg⁻¹ in a single genotype (Wissuwa *et al.* 2006; Wissuwa *et al.* 2008). The seed Fe and Zn concentrations did not increase in plants grown under Fe-deficient conditions in calcareous paddy fields or under Fe-sufficient conditions in andosol paddy fields (Masuda *et al.*, 2008; Suzuki *et al.*, 2008a). If driven by a suitable promoter, it can result in a significant increase in grain Fe (Ishimaru *et al.*, 2010).

Polished rice seeds with IDS3 inserts had up to 1.40 and 1.35 times higher Fe and Zn concentrations, respectively, compared to non-transgenic rice seeds. Enhanced MAs production due to the introduced barley genes is suggested to be effective for increasing Fe and Zn concentrations in rice grains (Masuda *et al.*, 2008). Jat *et al.* (2011) found that application of 2% Zn-enriched urea (ZnSO₄.7H₂O) was the best in

terms of all the yield attributes, grain yield of aromatic hybrid rice. In respect to Zn concentrations in grain and straw of aromatic hybrid rice, 2% Zn-enriched urea ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) recorded higher Zn concentrations in grain as well as in straw of aromatic hybrid rice. Over all grain yield was increased by all treatments compared with the control and it was highest with 11 kg Zn as zinc frits followed by zinc sulphate. Leaf Zn content ranged from 5.5 ppm in the control to 13.4 ppm with zinc sulphate application. Grain yield was significantly correlated with leaf Zn content (Subbaiah *et al.*, 1994).

Tripathi (1993) at Varanasi observed significantly more dry matter yield of rice with combined soil application of 10 mg kg^{-1} Zn and 10 mg kg^{-1} Fe. Fe with Mn application increased rice yield on silicon treated soil (Verma and Minhas, 1989). Crops as well as crop cultivars vary in respect of micronutrient density (Singh *et al.*, 2004). Quality also appears to be dependent on historical, socioeconomic and cultivar adaptation. In fact it is due to high Fe concentration in the inner skin of grains of red rice. However, Zn concentration is higher inside the polished grain. The aromatic cultivars have constantly higher Fe concentration in grain and also have more Zn than non aromatic types. It was observed that traditional cultivars had better Zn and Fe concentration in grain than high yielding new cultivars. Jalmagna had almost double the amount of Fe present in IR- 36 and IR-64 and Zn concentration was about 40% higher than IR-64. Mobilization of micronutrients from vegetative tissues to grain can form a significant source of micronutrients but little is known about mechanism governing such mobilization (Pearson and Rengel, 1994). Red rice genotype had higher Zn concentration than white genotypes. Unpolished red rice had higher Fe and Mn than unpolished white rice grain (Qui *et al.*, 1993).

Application of Zn significantly enhanced the yield of rice and available soil and plant Zn irrespective of Fe application. Maximum response of rice to Zn was obtained when Fe was applied at the highest rate. While Fe application brought about a significant improvement in available soil and plant Fe and Mn, it decreased significantly Zn content of the crop. After crop harvest, recovery of added Fe was 20% and Zn 12%. Results suggested that benefits of Fe application to rice in sodic soils could only be realised if it was applied along with Zn (Swarup, 1993).

2.9 Improving supply and acquisition of Zinc

Apart from the incorporation of fertilizers, adequate supply of organic matter is known to increase availability of almost all the nutrients including the zinc. High molecular weight organic carbon exudates released into the rhizosphere, activates micro-organisms activities around roots and may indirectly affect the solubility and availability of micro nutrients (Curl and Truelove, 1986; Marschner, 1995). Micro organisms present in the rhizosphere are known to produce better plant growth by enhancing nutrient availability.

In addition to specific Zn fertilizers, organic manures such as farm yard manure, compost, vermicompost, biogas slurry and crop residues are the good sources of Zn and other micronutrients and their continued application is known to maintain micronutrient deficiencies away or at least to reduce their occurrence. References pertaining to effect of applied organic matter *i.e.* Green manuring, chelated materials are well documented.

2.9.1 Soil application of Zinc

In calcareous soil, the soil application of Zn resulted in marked increase in grain yield (Serry *et al.*, 1974). Increased production of number of effective tillers, plant height, length of panicle, number of grains per panicle, test weight and grain and straw yield with increasing levels of ZnSO_4 applied as soil proved superior to its foliar spray (Panda and Nayak, 1974). Zinc application together with gypsum showed much effectively (Takkar and Singh, 1978). Since rice is prone to Zn deficiency under cold weather conditions, soil application of zinc proved superior to foliar spray. Incorporation of $60 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ as soil application gave highest grain and straw yield associated with maximum number of ear bearing, tillers per m^2 , tallest plant, longest panicle, maximum number of grains panicle⁻¹ and maximum weight of 1000 grains, whereas foliar application showed no advantage over soil application of zinc. Krishnaswamy *et al.* (1994) and Sharma *et al.* (1982) concluded that soil application proved advantageous in building up soil Zinc status and left residual effects to the succeeding crops (Prasad and Kumar, 1993). Biswas and Dravid (2001) recommended the application of $25 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ at puddling under normal soil conditions.

Methods of applications of Zn also depends upon the use of Zn fertilizer. Soluble Zn fertilizers such as ZnSO_4 , incorporated as band placement proved much superior to its broad cast application, whereas relatively less soluble fertilizers such as ZnO and Zn frits also showed better response as broadcast application (Katyal *et al.*, 2004; Rathore *et al.*, 1995). For low land rice broadcast application of 1 kg Zn-EDTA at puddling proved effective. The highest mean Zn uptake by rice grain and straw recorded to be 209.2 and 133.8 g ha^{-1} respectively (Naik and Das, 2008).

2.9.2 Foliar application of Zinc

Foliar application of zinc is often used for quick correction of severe Zn deficiencies. (Martens and Westernmann, 1991). Foliar application of zinc is usually applied under emergencies to save the crops if symptoms of Zinc deficiencies appear. However, single foliar application may not be adequate for correcting moderate to severe Zn deficiency. Foliar application of 0.5% aqueous solution of ZnSO_4 twice at 20 and 30 DAT proved superior to its soil application of 40 kg $\text{ZnSO}_4 \text{ ha}^{-1}$ in sodic soils (Dargan *et al.*, 1982). They further reported marked increase in the number of effective tillers, plant height, with increasing levels of ZnSO_4 applied either as soil or foliar proved. Application of 25 kg $\text{ZnSO}_4 \text{ ha}^{-1}$ significantly increased numbers of panicle/ m^2 , length of panicles, test weight, effective grains panicle $^{-1}$ and grain yield of rice over control, but remained at par with seeding roots dipped in 2% ZnSO_4 suspension and spraying of 0.5% ZnSO_4 solution at 3 and 5 week after transplanting (Kumar and Singh, 1996). The application of Zn @ 2.53 kg ha^{-1} as foliar spray significantly produced higher grain yield over soil application and control (Singh and Jain, 1964). While evaluating different methods of Zinc application, Zn applied at the rate of 25 kg $\text{ZnSO}_4 \text{ ha}^{-1}$ on transplanting (Zn_1), 0.5% as foliar spray at 30 days after transplanting (Zn_2), 0.5% as foliar spray at 30 and 45 DAT (Zn_3) and root dipping in 2.5 % solution for 24 hours before transplanting (Zn_4), it was observed that soil application produced significantly higher grain and straw yields (Singh *et al.*, 2005).



MATERIALS AND METHODS

A field experiment entitled “**Effect of crop establishment method and different source of Zinc on growth, yield and quality of rice (*Oryza sativa* L.) cv, PUSA-44**” was conducted during rainy season of 2013 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The detail of material used and method employed during the course of present investigation are presented here as under

3.1 Experimental site

The Agricultural Research Farm is situated in the south-eastern part of Varanasi city at a distance of about 10 km from Varanasi Cant railway station. Geographically, experimental site falls under sub-tropical zone of Indo-Gangatic plains and lies on the left bank of river Ganga. It is located on 25° 18'N latitude, 83 ° 03'E longitudes and at an altitude of 128.93 meters above mean sea level. The experimental plot was homogenous in fertility having assured irrigation and other required facilities.

3.2 Climate and weather

Varanasi falls in the belt of semi-arid to sub-humid climate receiving a mean annual rainfall of 1100 mm and potential evapo-transpiration of about 1525 mm. Thus, there is a moisture deficit of 425 mm. The normal period for the onset of monsoon in this region is the third week of June and which lasts up to the end of September or sometimes extends to the first week of October. However, occasional showers are also common during winters. The winter months are cool whereas summers are hot and dry. Standard week wise data on meteorological parameters were obtained from the meteorological observatory of the All India Co-ordinate

Research Project on Dryland Agriculture, Banaras Hindu University, Varanasi. A standard week-wise data on weather parameters are presented in Table 3.1.

Table 3.1: Meteorological observations (standard week- wise) during the crop season 2013.

Week No.	Month	Date	Rainfall (mm)	Temperature (°C)		R.H. (%)		Wind Speed km hr ⁻¹	Sunshie (hrs.)	Evaporation (mm)
				Max.	Min.	Max.	Min.			
24	June	11-17	6.7	38.0	28.0	73	48	8.7	5.8	5.9
25		18-24	31.8	35.3	27.3	82	65	3.2	3.9	4.6
26		25-01	134.4	30.7	25.7	82	74	8.5	2.8	3.7
27	July	02-08	39.4	33.3	26.7	82	71	2.5	4.0	3.2
28		09-15	81.5	32.2	26.6	86	72	3.9	3.4	3.5
29		16-22	0.0	34.8	28.3	83	67	5.9	6.9	5.0
30		23-29	48.2	32.2	26.3	86	77	6.6	5.8	4.3
31		30-05	69.5	32.5	25.5	84	75	5.8	6.7	4.3
32	Aug	06-12	28.6	32.5	26.0	91	76	3.7	4.6	4.1
33		13-19	37.4	31.8	25.7	88	80	2.4	6.9	3.8
34		20-26	32.3	32.1	26.2	83	74	5.3	6.9	4.2
35		27-02	150.3	28.7	25.7	92	87	3.0	1.5	2.5
36	Sep	03-09	3.2	32.5	25.3	80	66	4.2	7.6	3.7
37		10-16	0.0	33.7	26.9	85	66	1.9	7.2	3.7
38		17-23	4.6	31.6	25.3	81	76	5.2	8.0	3.9
39		24-30	12.2	31.6	25.5	86	77	2.8	6.8	2.9
40	Oct	01-07	83.9	28.8	24.3	93	85	5.9	3.9	3.3
41		08-14	44.0	29.1	23.8	84	78	5.5	6.5	2.6
42		15-21	17.0	26.7	21.1	92	80	1.5	4.2	1.7
43		22-28	0.0	29.6	21.1	88	72	2.2	8.9	2.9
44		29-04	0.0	28.6	17.3	80	76	1.6	7.8	2.3
45	Nov	05-11	0.0	27.7	15.5	84	60	0.6	7.6	1.6

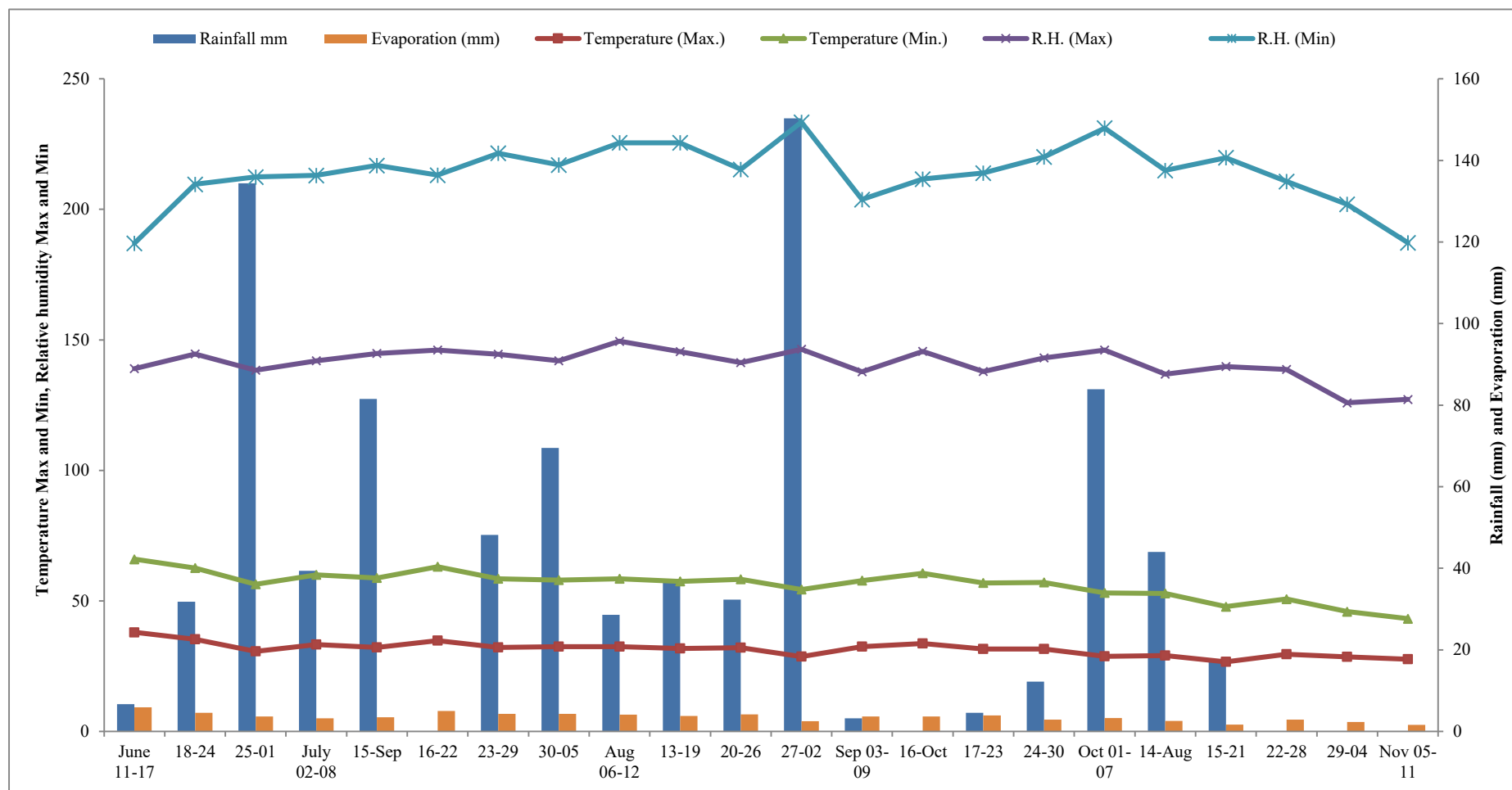


Fig 3.1 Meteorological observations (Standard week wise) obtained from the Meteorological observatory of the, Banaras Hindu University, during experimental period (2013-14)

The details of different meteorological parameters are given below:

3.2.1 Temperature (°C)

The weekly mean maximum and minimum temperature during the experimentation ranged from 26.7 to 38.0 °C and 15.5 to 28.3 °C, respectively. The maximum temperature was recorded 38.0 °C in 24th standard week in the month of June whereas, the lowest minimum temperature 15.5 °C in the 45th standard week of November.

3.2.2 Rainfall (mm)

The cumulative rainfall during the period of investigation in the cropping year 2013 (12 June to 11 Nov.) was 825 mm. The pattern of rainfall distribution was erratic during the experimental period. The highest rainfall (150.3 mm) was recorded during the meteorological week No. 35.

3.2.3 Relative humidity (%)

The weekly maximum relative humidity ranged between 73 to 93 per cent and minimum relative humidity varied from 48 to 87 per cent during the period of experimentation.

3.2.4 Sunshine duration (hours)

The average duration of bright sunshine was 5.50 hours. The maximum and minimum weekly bright sunshine duration ranged between 8.9 to 1.5 hours, respectively during the period of investigation.

3.2.5 Evaporation (mm)

The evaporation data obtained from weather bureau class A pan Evaporimeter revealed that average evaporation during the crop period ranged from 5.9 to 1.6 mm day⁻¹.

3.3 Soil and soil analyses

The alluvial soils of Indo-Gangetic plains in general are deep, flat, well drained with low available nitrogen and medium in available phosphorus and potassium. In order to evaluate the initial fertility status and to know about physical and chemical properties of the experimental plot, soil samples (0-15 cm depth) were randomly taken with the help of soil auger to make a composite sample. The soil samples were then analyzed for mechanical composition and chemical properties and the results are presented in Table 3.2.

Table 3.2: Mechanical and physico-chemical analyses of soil of the experimental fields

Particulars	Value	Method employed
(a) Physical properties of soil		
<i>Soil properties (%)</i>		
Sand	50.51	Hydrometric method (Bouyoucos, 1962)
Silt	25.83	
Clay	22.64	
Textural class	Sandy clay loam	Textural triangle (Black <i>et al.</i> , 1965)
Bulk density (g cc ⁻¹)	1.45	Core sampler (Piper, 1966)
True density (g cc ⁻¹)	2.63	
(b) Chemical properties of soil		
Organic carbon (%)	0.41	Walkley and Black rapid titration method (Jackson, 1973)
pH	7.25	Buckman pH meter (Jackson, 1958)
Electrical conductivity (ds m ⁻¹) at 25 ⁰ C	0.245	Systronics electrical conductivity meter (Jackson, 1973)
Available nitrogen (kg ha ⁻¹)	198.05	Alkaline permanganate method (Subbiah and Asija,1973)
Available P ₂ O ₅ (kg ha ⁻¹)	23.64	Olsen’s method 0.5 N NaHCO ₃ extractable (Olsen <i>et al.</i> , 1954)
Available K ₂ O (kg ha ⁻¹)	207.5	Flame photometric method (Jackson,1958)
Available zinc (ppm)	0.50	Extraction with DTPA solution (Lindsay and Norvell, 1978)

It is evident from the table that the soil of the experimental field is sandy clay loam in texture, neutral in reaction, low in available nitrogen and medium in available phosphorus and potassium.

It is quite evident from the data that the soil of the experimental field was sandy clay loam (typical Ustochrepts) in texture, deep, flat, well drained and moderately fertile being low in available nitrogen and phosphorus, and medium in available potassium.

3.4 Cropping history

The production potential of the experimental field can be judged from its cropping history, the details of cropping history of the experimental field prior to present experiment has been given in Table 3.3

Table 3.3: Cropping history of the experimental field

Year	Kharif	Rabi
2008-09	Rice	Wheat
2010-11	Rice	Wheat
2011-12	Rice	Wheat
2012-13	Rice (Experimental crop)	

It is quite apparent from the cropping history of the experimental site that the field has been continuously under cereal-cereal cropping sequence and its fertility set up has not been disturbed. Hence, as such the field is ideally for the experiment.

3.5 Experimental details

3.5.1 Experimental design and layout

Considering the nature of factors under study and the convenience of agricultural operation, the experiment was laid out in Split Plot Design assigning

three main plot treatments as Crop Establishment Method System of Rice Intensification (SRI), Wetland transplanting, Farmer's practice's and four sub plot treatment as Different Source of Zinc $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (21% Zn), Zn-EDTA (12% Zn), $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ (33% Zn). The whole field was divided into three replication. Each replication is further divided into three main plot and four sub plot in which treatments were allocated randomly.

3.5.2 Treatment details

The classified description of the treatment with corresponding symbols in order to facilitate their reference in the text is given in Table 3.4.

Table 3.4: Treatment detail

Treatment	Symbol used
Main Plot: Method of Crop Establishment	
SRI	M₁
Wetland Transplanting	M₂
Farmer's Practice	M₃
Sub Plot : Different Source of Zinc	
Control	Z₀
$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (21% Zn)	Z₁
Zn – EDTA (12%Zn)	Z₂
$\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ (33%Zn)	Z₃

RDF= Recommended dose of fertilizer (NPK) - 120-60-60 kg ha⁻¹

Zn @ 10 kg ha⁻¹ applied as basal (1/2) and foliar (1/2) through, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (21% Zn), and 5.0 kg Zn applied through $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ (33%Zn) as basal (1/2) and foliar (1/2).

Zn @1.0 kg ha⁻¹ applied as basal (1/2) and foliar (1/2) through Zn-EDTA (12% Zn).

Table 3.5 : Details of layout plan

Experimental design	Split Plot Design
Treatment combinations	$3 \times 4 = 12$
Number of replications	03
Total number of plots	$12 \times 3 = 36$
Gross plot size	$5 \text{ m} \times 4 \text{ m} = 20 \text{ m}^2$
Net plot size	SRI $4.5 \text{ m} \times 3.0 \text{ m} = 13.5 \text{ m}^2$ Other $4.5 \text{ m} \times 3.2 \text{ m} = 14.4 \text{ m}^2$
Replication border	1.5 m
Main irrigation channel	1.5 m
Sub irrigation channel	1.0 m
Main plot border	1.0 m
Sub plot border	0.5 m
Field plot border	1.5 m
Spacing	1.5m $25 \times 25 \text{ cm}$ for SRI $20 \times 15 \text{ cm}$ for both WT and Farmer's practice.

Table 3.6 Treatment combinations (12) tested under experiment

T ₁	M ₁ Z ₀
T ₂	M ₁ Z ₁
T ₃	M ₁ Z ₂
T ₄	M ₁ Z ₃
T ₅	M ₂ Z ₀
T ₆	M ₂ Z ₁
T ₇	M ₂ Z ₂
T ₈	M ₂ Z ₃
T ₉	M ₃ Z ₀
T ₁₀	M ₃ Z ₁
T ₁₁	M ₃ Z ₂
T ₁₂	M ₃ Z ₃

3.6 Selection of variety

3.6.1 Pusa-44

It is a semi dwarf, medium maturity, non-aromatic rice variety suitable for cultivation in irrigated areas of U.P. Its maturity duration is 140-145 days, average yield potential is up to 22-24 q acre⁻¹. Plant grows up to height of 100-110 cm.

3.6.2 Sources of nutrients

Inorganic sources

1. Urea

Urea is most widely used N fertilizer and is produced by heating ammonia with CO₂ under high temperature (160-170 °C). Urea contains the highest percentage of nitrogen (46.0%) among solid fertilizers. It contains nitrogen in the amide form. This Organic fertilizer is cheaper than any other solid nitrogenous fertilizer in India.

2. DAP

Di-ammonium phosphate is the most widely used phosphatic fertilizer and is produced by reacting calcium nitrate with mono-calcium phosphate and finally to di-Ammonium phosphate and it contains 18% N and 46% P₂O₅.

3. MOP

Muriate of potash or potassium chloride (KCl) is most common and cheapest fertilizer among the potassic fertilizers. It contains 60% K₂O.

3.7 Agronomic practices

Detail of the operations carried out to get the field prepared for rice during the entire period of investigation are described below and calendar of field operations are given in Table 3.7.

Table 3.7: Details of field operations carried out during experiment.

S. No.	Operations	Date
1.	Nursery raising	
	(a) Pre-sowing irrigation	18-06-2013
	(b) Ploughing	24-06-2013
	(c) Puddling	28-06-2013
	(d) Manuring	28-06-2013
	(e) Sowing	28-06-2013
	Irrigation	
	(a) 1 st	01-07-2013
	(b) 2 nd	07-07-2013
	(c) 3 rd	18-07-2013
2.	Preparatory tillage	
	(a) 1 st	04-07-2013
	(b) 2 nd	07-07-2013
3.	Puddling	
	(a) SRI	09-07-2013
	(b) WT and Farmer Practice	23-07-2013
4.	Lay out of experiment	
	(a) SRI	10-07-2013
	(b) WT and Farmer practice	24-07-2013
5.	Incorporation of FYM to the soil	10-07-2013
6.	Transplanting in SRI	12-07-2013
7.	Transplanting in WT and Farmer practice	26-07-2013
8.	Fertilization application in SRI	
	(a) Basal application of NPK	12-07-2013
	(b) 1 st top dressing	11-08-2013
	(c) 2 nd top dressing	15-09-2013

Contd...

S. No.	Operations	Date
	Application of Zinc	
	(a) Basal application of Zinc	12-07-2013
	(b) Foliar application of Zinc	11-08-2013
9.	Fertilizer application in WT and transplanting	
	(a) Basal application of NPK	26-07-2013
	(b) 1 st top dressing	25-08-2013
	(c) 2 nd top dressing	30-09-2013
	Application of Zinc	
	(a) Basal application of Zinc	26-07-2013
	(b) Foliar application of Zinc	25-08-2013
10.	Inter culture and weed management	
	(A) SRI through Conoweeder	
	(a) 1 st	02-08-2013
	(b) 2 nd	25-08-2013
	(B) WT and farmer practice	
	(a) Hand weeding	25-08-2013
11.	Irrigation application	
	(A) SRI	
	(a) 1 st	08-08-2013
	(b) 2 nd	11-09-2013
	(c) 3 rd	10-10-2013
	(B) WT and Farmer practice	
	(a) 1 st	22-08-2013
	(b) 2 nd	11-09-2013
	(c) 3 rd	10-10-2013
12.	Harvesting	
	(a) SRI	15-11-2013
	(b) WT and Farmer practice	22-11-2013
13.	Bundling	27-11-2013
14.	Threshing and recording of grain and straw yield	12-12-2013

3.7.1 Nursery raising

The nursery area was ploughed thrice, leveled and described seedbed was prepared. Soil moisture condition favourable to seedling growth was provided and bed was uniformly fertilized. Certified seeds of rice genotype 'PUSA-44' were procured. The seeds were soaked in water for 12 hours and subsequently were sown in the nursery on puddle bed by broadcast method adopting the recommended seed rate of 30 kg ha⁻¹. A thin film of water was maintained continuously for two days and thereafter it was drained off. Optimum soil moisture was maintained in the nursery for satisfactory growth.

3.7.2 Field preparation

Proper field preparation is essential for a healthy rice crop. The experimental area was ploughed with tractor just after harvest of winter crop and ploughed again in the 1st week of July. Thereafter, the field was puddled with cage wheel and leveled and finally the experiment was laid out to meet the experimental design.

3.7.3 Transplanting

Four week old-seedlings were transplanted on the puddled field at the rate of 2-3 seedling hill⁻¹ in Wetland and Farmer practice method of rice. Row spacing of 20 × 15 cm was maintained under Wetland and farmer practices but in SRI method of transplanting 12-14 days old seedling were transplanted on the puddle field at the rate of 1 seedling hill⁻¹. Row spacing of 25 × 25 cm was maintained under SRI..

3.7.4 Fertilizer application

Fertilizer application to the test crop was done adopting the recommended fertilizer dose (RDF) for Varanasi region i.e. N - P₂O₅ - K₂O (120-60-60 kg ha⁻¹). Fertilizer application was done as per treatments. Half of the recommended dose of nitrogen and full dose of Phosphorus and Potassium were applied as basal application uniformly to all the treatments and remaining half nitrogen was applied in two equal splits at active tillering and panicle initiation stages. The rate of Zinc was applied as per treatment 10 Kg Zn ha⁻¹ as (1/2) soil application and as (1/2) foliar application

(1%) through $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (21% Zn) and $5.0 \text{ kg Zn ha}^{-1}$ was applied as (1/2) soil application and as (1/2) foliar application (0.5%) through $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ (33% Zn) and Zn-EDTA (12% Zn) was applied @ $1.0 \text{ kg Zn ha}^{-1}$ as (1/2) basal and as (1/2) foliar (0.5%) to rice crop.

3.7.5 Irrigation

Irrigation was given to the crop as and when needed according to the crop requirement and rainfall pattern. Throughout the crop period, three irrigations were given and about $\pm 5 \text{ cm}$ water level was continuously maintained till flowering and after that field was kept under saturated condition.

3.7.6 Weeding

One manual weeding at 20-25 DAT was done to keep the field free from weeds under Wetlands and Farmer practice but in case of SRI, 2-3 weeding done as per requirement of rice crop through Conoweder.

3.7.7 Harvesting and threshing

The crop was harvested at proper maturity. Plants from the net plot were harvested, bundled separately and tagged. Each bundle was weighed after complete drying in the sun, threshed and grain yield was recorded after winnowing and cleaning. The straw yield was calculated by subtracting grain yield from the bundle weight and was converted to q ha^{-1} based on net plot size.

3.8 Biometric observation

For recording biometric observations at a regular interval of 30th, 60th, 90th days after transplanting (DAT) and at harvest, five hills in the net plot area randomly selected and tagged. However, for the dry matter accumulation, five hills were randomly selected from the sample row (border row) at mentioned interval. Yield attributes and yield were studied before and after harvesting as per investigation required.

3.8.1 Growth attributes

3.8.1.1 Plant height (cm)

The height of plants from five randomly selected tagged hills were measured at 30, 60, 90 days transplanting and at harvest from the base of the plant to the tip of the upper most fully opened leaf. After panicle emergence, the height was measured up to the tip of the panicle.

3.8.1.2 Number of the tillers (hill⁻¹)

Tillers were counted from 5 tagged hills at 30, 60, 90 days after transplanting and at harvest from each plot to compute average number of tillers hill⁻¹.

3.8.1.3 Dry matter accumulation hill⁻¹ (g)

Five hills were randomly selected from the sampling rows (two border rows from the each side) at regular interval (30, 60, 90 DAT and at harvest). The plants were cut from ground level, sun dried thereafter the collected samples were oven dried at 70°C for 48 hours to constant weight. The weight thus obtained was recorded as average dry weight hill⁻¹ (g) after dividing the total weight of five hills by the total number of hills (05).

3.8.1.4 Leaf area index (LAI)

The leaf area index (LAI) was obtained by using leaf canopy meter. The leaf area index was obtained by dividing the actual leaf area obtained hill⁻¹ with the ground area occupied by the hill⁻¹.

$$\text{LAI} = \frac{\text{Leaf area hill}^{-1} (\text{cm}^2)}{\text{Land area (cm}^2\text{) covered by single hill}}$$

3.8.1.5 Chlorophyll content

The SPAD 502, a hand held chlorophyll meter or SPAD meter (Minolta Corporation, Ramsey, NJ) was used for rapid and non-destructive estimation of extractable chlorophyll in leaves (Earl and Tolleraar, 1997). It is a simple, portable diagnostic tool that measures the greenness or relative chlorophyll content of leaves (Inada, 1985). Meter reading are given in Minolta Company-defined SPAD (soil plant analysis development) unit that indicate relative chlorophyll contents (Balasubramanian *et al.*, 2000). This instrument uses a silicon photo diode to detect transmittance of light emitted by two light emitting diodes through a leaf sample, one with peak emittance at 650 nm, where absorbance by chlorophyll is high and relatively unaffected by carotene and one with peak emittance at 940 nm where absorbance by chlorophyll is negligible. The SPAD reading, which is correlated with leaf chlorophyll concentration, is calculated from the transmittance through leaf tissue at these two wavelengths. Chlorophyll content was measured at 45, 60, 90 DAT and at harvest. The youngest fully expanded leaf of a plant was used for SPAD measurement. Readings were taken on one side of the midrib of the leaf blade, midway between the leaf base and tip. A mean of 10 readings per plot was taken as the measured SPAD value.

3.8.2 Yield attributes

The following observations on yield attributes and yield studies were recorded during the experimentation:

3.8.2.1 Panicle length (cm)

Ten panicles were randomly selected from tagged plants and the length was measured from the neck node to the tip of the upper most spikelet and average length was recorded.

3.8.2.2 No. of panicles m⁻²

It was counted by placing 0.25 m² quadrat at two places randomly in each net plot at complete maturity of the crop and were averaged over to find out averaged number of spike which came within the quadrat.

3.8.2.3 Filled grains panicle⁻¹

Grains of ten randomly selected panicle from each plot were separated and counted and their mean value expressed as average grain per panicle.

3.8.2.4 Panicle weight (g)

Ten randomly selected panicles were weighted and after taking average recorded as panicle weight.

3.8.2.5 1000 grains weight (g)

Grain samples were taken from the threshed and cleaned produce of each net plot and 1000 grains were counted and weighed.

3.8.2.6 Grain yield (q ha⁻¹)

The mature harvested produce from the net plot area was sun dried and threshed to obtain grain yield grain in kg plot⁻¹. Thereafter, it was computed to q ha⁻¹.

3.8.2.7 Straw yield (q ha⁻¹)

The straw yield was worked out by subtracting the grain yield from total biological yield and finally it was computed to q ha⁻¹.

3.8.2.8 Harvest Index (%)

Harvest index (HI) was computed as the ratio of economic yield i.e. grain yield to the total biomass i.e. biological yield (grain + straw) from same area and expressed in percentage.

It was calculated by using formula suggested by **Donald (1958)**.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

$$\text{Biological yield} = \text{Grain yield} + \text{Straw yield}$$

3.8.3 Chemical analysis of plant

3.8.3.1 Nutrient uptake studies

At harvest, the plant and grain samples were collected from each plot for chemical estimation and the samples were dried in an oven at 70°C for 48 hours, the plant material thus obtained was ground with the help of grinder and passed through 40 mesh sieve and preserved separately for determination of N, P and K content. The nutrient content was then estimated as per following methods as given in the Table 3.8.

3.8.3.1.1 Nitrogen

Nitrogen content (%) was estimated both in grain and in straw by modified Kjeldahl method as described by Jackson (1973). Total nitrogen content in grain and straw was multiplied by the respective dry matter yield to get the total nitrogen uptake (kg ha^{-1}) by plants.

3.8.3.1.2 Phosphorus

Phosphorus content (%) in grain and straw was determined by Vandomolybdo phosphoric acid yellow color method as suggested by Jackson (1973). Total phosphorus content of grain and straw was multiplied by the respective dry matter yield to get the total phosphorus uptake (kg ha^{-1}) by plants.

3.8.3.1.3 Potassium

Potassium content (%) was estimated with the help of Flame photometer as described by Jackson (1973). Potassium per cent in grain and straw were multiplied by their respective dry matter yield to obtain total potassium uptake (kg ha^{-1}) by plants. The uptake of all the major nutrient in kg ha^{-1} was calculated by using the formula given by Black (1965)

Table 3.6: Methods of plant chemical analysis

Nutrient	Analytical method	References
Nitrogen	Micro Kjeldhal method	Jackson (1973)
Phosphorus	Vanado molybdate phosphoric acid yellow colour method	Jackson (1973)
Potassium	Flame-photometric method	Jackson (1973)
Zinc	Atomic Absorption Spectrophotometer Method	Lindsay and Norvell (1978)

3.8.3.1.4 Nutrient removal (kg ha⁻¹)

Nutrient removal by grain and straw of rice crop was calculated in kg ha⁻¹ in relation to dry matter production ha⁻¹ by using following formula (Black, 1967).

$$\text{Removal (kg ha}^{-1}\text{)} = \frac{\text{Nutrient (\%)} \text{ in grain /straw} \times \text{grain / straw yield (kg ha}^{-1}\text{)}}{100}$$

3.8.3.1.5 Nutrient Uptake

Nutrient uptake by grain, straw and total (grain + straw) were calculated in kg ha⁻¹ from their corresponding yield and nutrient content by using following formula:

$$\text{Nutrient removal (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Total dry matter yield (Kg ha}^{-1}\text{)}}{100}$$

3.9 Quality parameters

The analyses of grain samples for quality parameters were entirely carried out in the Biochemistry division of Central Rice Research Institute (CRRI) Cuttack, Odisha. The standard procedures as described below were followed.

3.9.1 Protein content (%)

Protein content (%) in grain was worked out by multiplying the nitrogen content in grain by the factor 6.25 (A.O.A.C, 1995).

3.9.2 Protein yield (kg ha⁻¹)

The protein yield (kg ha⁻¹) was obtained by the following formula:

$$\text{Protein yield (kg ha}^{-1}\text{)} = \text{Protein content}(\%) \times \text{yield (kg/ha}^{-1}\text{)}$$

3.9.3 Hulling and Milling Percentage

Hundred gram sample of unhusked rice from each plot was subjected to dehusking in a SATAKE dehusker. The dehusked caryopses were weighed and percentage was determined by the following formula:

$$\text{Hulling percentage (\%)} = \frac{\text{Weight of the dehusked caryopsis}}{\text{Weight of paddy}} \times 100$$

Dehusked kernels were then put into a Kett T-2 polisher. Time of the polisher was adjusted in such away that per cent polishing is 5% (approx.). Total polished kernels were weighted and then milling percentage was calculated by the following formula (Ghosh *et al.*, 1971).

$$\text{Milling percentage (\%)} = \frac{\text{Weight of the polished kernel}}{\text{Weight of unpolished rice}} \times 100$$

3.9.4 Head rice recovery (HRR) Percentage (%)

The polished kernels were then passed through rice grader having 5 mm grooves to separate whole grains from the broken ones in order to quantify the head rice recovery. If the grain was broken in two parts, then one-half of the grain was counted as one full grain. The process was repeated for three times. The percentage of

the head rice recovery was calculated as per the following formula (Ghosh *et al.*, 1971).

$$\text{Head rice recovery (\%)} = \frac{\text{Weight of whole polished grains}}{\text{Weight of unhusked rice}} \times 100$$

3.10 Economics

The cost of cultivation was worked out by taking into consideration all the expenses incurred. The cost of input and price of produce prevalent at the Agricultural Research Farm, Banaras Hindu University were taken into consideration for calculating economics of different treatments. Gross return was worked out by multiplying grain and straw yield with their prevailing market prices and expressed in rupees per hectare.

3.10.1 Gross return (Rs ha⁻¹)

The yield of rice crop was converted into gross return in rupees per hectare on the basis of current price of the produce.

3.10.2 Net returns (Rs ha⁻¹)

The net return was worked out by using following formula:

$$\text{Net return (Rs)} = \text{Gross return (Rs)} - \text{cost of cultivation (Rs)}$$

3.10.3 Benefit cost ratio (BCR)

The benefit cost ratio was calculated on the basis of net return per unit cost of cultivation (Rs).

$$\text{BCR} = \frac{\text{Net return (Rs.)}}{\text{Cost of cultivation (Rs.)}}$$

3.11 Statistical analysis

The observation recorded during the course of investigation were tabulated and analyzed statistically to draw a valid conclusion. The data were analyzed as per the standard procedure for “Analysis of Variance” (ANOVA) as described by Gomez(1984). The significance of treatments were tested by ‘F’ test (Variance ratio). Standard error of mean was computed in all cases. The difference in the treatments mean were tested by using Least Significance Difference (LSD) at 5% level of probability where ‘F’ test showed significant difference among means by the following formula

$$\text{S.Em. } \pm = \sqrt{\frac{\text{Error sum of square}}{n}}$$

Where,

n = number of observations

CD at 5% = S.Em. $\pm \sqrt{2}$ $\times$ t value at 5% error degree of freedom

ANOVA Table

Source of variation	Degree of Freedom	Sum of squares	Mean sum of squares	Cal. F value	Tab. F value
Replication	2				
MPT (Method of crop stablishment)	2				
Error a (Rep x MPT)	4				
SPT (Different sources of Zn)	3				
MPT X SPT (Interaction)	6				
Error b	18				
Total	35				



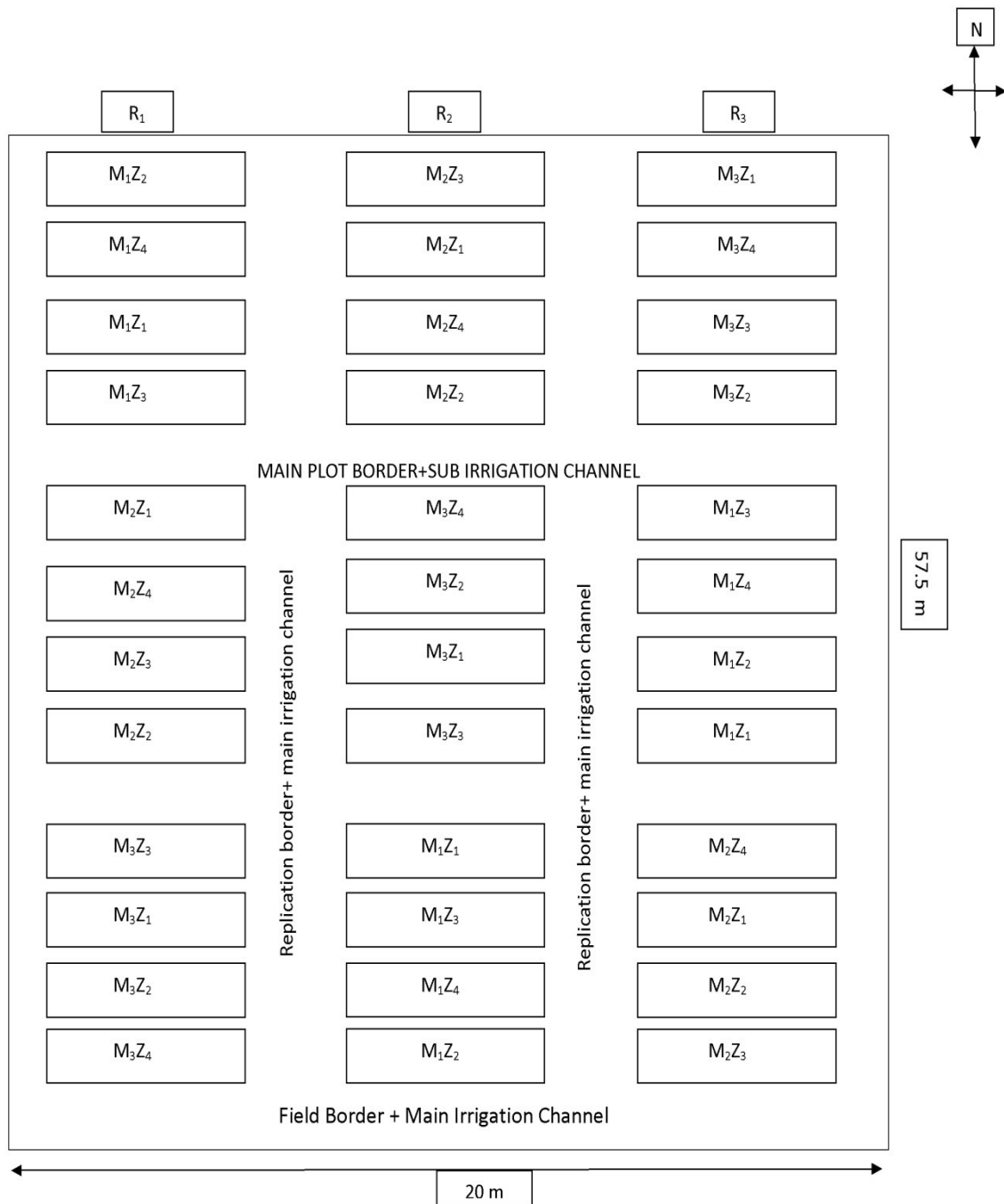


Fig. 3.1 Layout Plan (Split Plot Design)

EXPERIMENTAL FINDINGS

The present investigation entitled “**Effect of crop establishment method and different source of Zinc on growth, yield and quality of rice (*Oryza sativa* L.) cv Pusa-44**” was conducted during rainy (*kharif*) season of 2013 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (U.P.). In this chapter an attempt has been made to ascertain the degree of variation exhibited by the rice crop at successive stage of growth and development due to different crop establishment method and application of Zinc sources *viz.* Zn-SO₄.7H₂O, Zn-EDTA and ZnSO₄.H₂O. The observations recorded during the course of present investigation pertaining to growth, yield attributes along with nutrient uptake and economics are presented in this chapter with the help of Table-s and graph/ figures.

4.1 Growth parameters

4.1.1 Plant height (cm)

Height of the plant as affected by different treatment at different stage of growth (30, 60, 90 DAT and at harvest) are presented in Table- 4.1.

Perusal of the data revealed variation on plant height due to different method of crop establishment at all stages of growth. Among the crop establishment method, SRI showed significantly maximum plant height (79.06, and 101.65 cm) as compared to other method at 60 and 90 DAT but at 30 days after transplanting and at harvest there was found no significant difference in plant height. Concurrently minimum height of plants (44.04, 74.32, 97.73 and 96.45 cm) was recorded in farmer’s practice.

The data for different sources of Zinc showed that there was found no significant variation in plant height at 30 DAT but at 60, 90, and at harvest it showed significant variation in plant height due to application of different sources of Zn

element. Application of Z_2 (Zn-EDTA) @ of 1.0 kg Zn ha⁻¹ showed significantly maximum height of the plants (81.46, 103.69 and 100.09 cm) as compared to Z_1 (ZnSO₄.7H₂O) @ of 10.0 kg Zn ha⁻¹, Z_3 (ZnSO₄.H₂O) @ of 5.0 kg Zn ha⁻¹ and control plot. The minimum plants height (42.92, 69.83, 94.78 and 93.96 cm) was recorded in control plot.

4.1.2 Number of tiller hill⁻¹

The data on tillers hill⁻¹ recorded at regular interval are presented in Table 4.2.

Perusal of the data revealed that variation on No. of tillers hill⁻¹ due to different method of crop establishment at all the stages of growth. Among the crop establishment method, SRI showed significantly maximum No. of tillers hill⁻¹ (18.98) at 60 DAT as compare to other method but at (60, 90 DAT and at harvest) SRI and Wetland was recorded statistically at par with each other.

Data pertaining to Zinc application showed significant variation in No. of tillers hill⁻¹ was recorded significantly highest No. of tillers hill⁻¹ (10.38, 20.09, 18.74 and 16.87 cm) with the application of Z_2 (Zn-EDTA) @ 1.0 kg Zn ha⁻¹ as compare to other treatments but at harvest Z_2 and Z_1 was found statistically at par with each other. The minimum No. of tiller hill⁻¹ (7.19, 13.17, 14.13 and 12.32 cm) was recorded under control.

4.1.3 Number of leaves hill⁻¹

Data related to average number of leaves hill⁻¹ have been presented in table 4.3

A perusal of the data revealed the variation on No. of the leaves hill⁻¹ due to different method of crop establishment at all the stages of growth. Among the crop establishment method, SRI showed significantly maximum No. of leaves hill⁻¹ (30.49) at 30 DAT but at 60, 90 DAT and at harvest SRI and Wetland statistically at par with each other. The Minimum plant leaves was recorded under Farmer's practice (27.03, 53.72, 51.75 and 41.76) at all growth stages.

Data pertaining to Zinc application showed significant variation in No. of leaves hill⁻¹ (31.37, 67.48, 62.11 and 52.69cm) was recorded with the application of Z₂ (Zn-EDTA) @ 1.0 kg Zn ha⁻¹ as compare to other treatments at all growth stages. The minimum no. of leaves (24.98, 49.11, 51.11 and 38.38) was found under control plot.

4.1.4 Dry matter accumulation (g hill⁻¹)

The data on dry matter accumulation hill⁻¹ as influence by crop establishment method and different sources of Zinc are presented in Table- 4.4.

The results revealed that a consistent increase in the dry matter accumulation occurred with the advancement of the crop growth stage and reached to maximum level at time of maturity. The rate of increase in dry matter accumulation enhanced rapidly between 30 to 60 DAT followed by 60 to 90 DAT. The crop establishment method showed variation in production of dry matter. SRI showed maximum dry weight at all growth stage of observation. However, the dry matter was proved significantly superior in SRI at 60 and 90 DAT but at 30 DAT and at harvesting stage was statistically at par with each other. Minimum dry matter accumulation was recorded under control.

The data regarding different source of Zinc revealed that the significantly higher dry matter accumulation were recorded in Z₂ treatments at 60 DAT and at harvest as compare to other treatments. But at 30 and 90 DAT Z₂ and Z₁ were at par to each other. The Minimum dry matter accumulation was recorded under control.

4.1.5 Leaf area index

The data on leaf area index as affected by different source of Zinc are presented in Table- 4.5.

The results revealed that a consistent increase in the leaf area index occurred with the advancement of the crop growth stage and reached to maximum at time of 60 DAT. The rate of increase in leaf area index enhanced rapidly between 30 to 60 DAT.

It was evident from data the crop establishment method and different Zinc source significantly influenced the leaf area index. The significantly higher value was observed in SRI at 30 DAT but SRI and Wetland transplanted were statistically at par to each other at 60 DAT but at 90 DAT was recorded no significant difference to each other. The minimum LAI was recorded under Farmer's practices.

Data pertaining to different source of Zinc on LAI. The higher value was recorded with use of (Zn-EDTA) @ 1.0 kg Zn ha⁻¹ as compare to other treatments at 30 and 60 DAT but at 90 DAT there was found no significant difference. The minimum LAI was proved under control.

4.1.6 Chlorophyll contents

Data pertaining to chlorophyll content have been presented in table 4.6

A perusal of the data revealed that there was no variation on chlorophyll content due to different method of crop establishment at all the stages of plant growth. Among the crop establishment method, SRI showed maximum chlorophyll content in plant followed by wetland and farmer's practice. The minimum chlorophyll content was observed in Farmer's practice.

Perusal of the data observed that there was no significant variation on chlorophyll content due to different source of zinc (Zn) at all the growth stage. Overall, the chlorophyll content increased up to 60 DAT after which it was started declining. Among the source of zinc, Z₂ (Zn-EDTA) @ 1.0 kg ha⁻¹ produced leaves having higher chlorophyll content as compare to other treatments. The minimum chlorophyll content was recorded in control.

4.2 Yield attributes and yield

4.2.1 Number of panicle plant⁻¹

The data revealed that number of panicle plant⁻¹ of rice as influenced by various methods of crop establishment and application of different source of Zinc in the Table- 4.7

Significantly maximum number of panicle plant⁻¹ (15.02) was found in SRI. But SRI and wetland method of crop establishment was at par with each other. The minimum number of panicle plant⁻¹ was recorded under farmer's practice.

The data regarding different source of Zinc revealed that Z₂ (Zn-EDTA) was observed higher number of panicle plant⁻¹. But Z₂ and Z₁ was at par with each other. The minimum number of panicle plant⁻¹ (10.19) was recorded under control where it is no application of Zinc.

4.2.2 Panicle length (cm)

Data of panicle length of rice as influenced by various methods of crop establishment are presented in Table- 4.7.

A close examination of data revealed that panicle length differed due to crop establishment method and Zinc source and it increased with increase the different application of Zinc sources.

Maximum panicle length (26.81cm) was found significantly superior in SRI crop establishment method as compare to other method. The minimum panicle length (24.12) was found in Farmer's practice.

The data regarding to different source of Zinc on panicle length Z₂ (28.19) was revealed significantly superior over other treatment. The minimum panicle length was observed in Control.

4.2.3 Panicle weight (g)

The data revealed that panicle weight of rice as influenced by various method of crop establishment and application of different source of Zinc. Table- 4.7

The data proved that maximum panicle weight (4.83 g) was found in SRI crop establishment method as compare to other method but SRI and Wetland was at statistically at par with each other .The minimum panicle weight was found in Farmer's practice.

The data regarding different source of Zinc revealed that Z₂ (Zn-EDTA) was recorded maximum panicle weight (4.97g) as compare to other treatments. The minimum panicle weight was recorded under control.

4.2.3 Filled grain plant⁻¹

The data observes that grain Filled grain plant⁻¹ of rice as influenced by various methods of crop establishment and application of different source of Zinc. Table- 4.8

The data observed that SRI was recorded significantly higher filled grain (218.92) plant⁻¹ as compare to other treatments. The minimum filled grain plant⁻¹ (200.13) was recorded under farmer practice's method.

The data regarding different source of Zinc revealed that Z₂ (Zn-EDTA) application @ 1.0 kg Zn ha⁻¹ was recorded significantly superior filled grain (239.56) filled grain plant⁻¹ over other treatments like ZnSO₄.7H₂O and ZnSO₄.H₂O application of Zinc sources @ 10.0 kg Zn ha⁻¹ and 5.0 kg Zn ha⁻¹ each applied as basal (1/2) and foliar (1/2). The minimum filled grain (182.06) plant⁻¹ was recorded under control.

4.2.4 Sterility (%)

The data revealed that sterility (%) per plant of rice as influenced by various method of crop establishment and application of different source of Zinc. Table- 4.8

Data pertaining to sterility (%) revealed that there was no significant different. Maximum number of sterility (11.40%) was found in farmer's practice crop establishment method as compare to other method. The minimum sterility (%) was recorded under SRI.

The data regarding different source of Zinc on Sterility (%) revealed that Z₂ (Zn-EDTA) application @ 1.0 kg ha⁻¹ was observed significantly superior over all other treatments. The minimum sterility (%) was found in Z₂ treatments.

4.2.5 1000 grain weight (g)

The data examined that 1000 grain weight (g) of rice as influenced by various method of crop establishment and application of different source of Zinc. Table- 4.8

Data pertaining to 1000 grain weight (g) there was found no significant difference among treatments of rice, clearly showed that grain obtained from SRI (22.75 g) over all the other treatments. The minimum test weight (21.05 g) was recorded in farmer's practice.

Data pertaining to different source of Zinc variation there was no significant variance on test weight (g). The Z₂ was recorded higher test weight as compare to other treatments. The minimum test weight was recorded in control.

4.2.6 Grain yield (qha⁻¹)

The data on grain yield of rice as influenced by crop establishment method and Zn source have been presented in Table- 4.9

It is clear from the data that grain yield of rice followed the similar trend to growth and yield attributes. Seed yield increased in SRI method was recorded significantly higher grain yield (51.95 q ha⁻¹) as compare to other method. The minimum grain yield (47.67 q ha⁻¹) was recorded in Farmer practice's.

Data pertaining to Grain yield as influenced by different sources of Zinc. Z₂ was recorded significantly higher grain yield (54.31q ha⁻¹) as compare to other treatments. The minimum grain yield (44.04 q ha⁻¹) was recorded under control.

4.2.7 Straw yield (q ha⁻¹)

The straw yield of rice as influenced by crop establishment method and different source of Zinc have been compiled in Table- 4.9.

It is clear from the data that straw yield of rice followed the similar trend to growth and yield attributes. SRI crop establishment method was recorded

significantly maximum straw yield (60.96 q ha^{-1}) as compare to other method. The minimum straw yield was observed in farmer practice's (54.83 q ha^{-1}).

The data regarding to different source of Zinc on straw yield. The Z_2 was recorded significantly superior straw yield (61.56 q ha^{-1}) as compare to other treatments. The minimum straw yield was observed in control (54.04 q ha^{-1}) with other treatments.

4.2.8 Harvest Index (%)

The harvest index of rice as influenced by crop establishment method and application of different sources of Zinc have been presented in Table 4.9

It is clear from the data there is no significant difference on harvest index among all the treatments. A perusal of the data revealed variation on harvest index was proved higher in SRI followed by other method. The minimum harvest index was observed in Farmer's practice.

The data regarding to different source of Zinc revealed that there was no significant difference on harvest index. The treatment Z_2 recorded the maximum harvest index (47.10%) as compare to other treatments like Z_0 , Z_1 and Z_3 .

4.3 Nitrogen, Phosphorus and Potassium uptake in grain and straw of rice

Nutrient content

Data on N, P and K concentration (%) in rice grains at harvest stage as well as in straw pertaining to the different method of crop establishment and different source of Zinc treatments are presented in Table.4.10

In general all the treatments showed no significant variation in the nutrient concentration in grain and straw.

4.3.1 Nitrogen content (%)

4.3.1.1 Nitrogen content in grain (%)

Data pertaining to the nitrogen content in to the rice grain are presented in Table 4.10.

Data pertaining to N content (%) there was no significant different on N content (%) in grain. The N content (%) and grain yield showed inverse relationship. The highest N content (0.95 %) was recorded with farmer practice's methods and proved superior to M₁ and M₂ crop establishment method.

Data pertaining to different source of Zinc indicated that there is no significant difference among all the treatments but the higher N concentration (0.94 %) was recorded under control followed by Z₁, Z₂ and Z₃.

4.3.1.2 Nitrogen concentration in straw (%)

A critical observation of data revealed that the N content in the straw indicated no significant variation in the N content (%) in straw due to the different method of crop establishment presented in Table 4.10.

An increasing trend of N content (%) in straw was noted with the farmer's practice (0.49%) which was found higher than other method. The minimum N content in straw was observed in M₁.

Data pertaining to different source of Zinc indicated that there was no significant difference among all the treatments but the higher N concentration (0.49%) was recorded under control followed by Z₁, Z₂ and Z₃.

4.3.1.3 Uptake of nitrogen (kg ha⁻¹)

Data on nitrogen uptake in grain, straw and finally the total uptake with different crop establishment method and Zinc source are presented in Table- 4.10.

It was evident from the observation that there was no significant variation on uptake of nitrogen (kg ha^{-1}) by crop establishment method that maximum nitrogen uptake in grain (46.55 kg ha^{-1}) was found in SRI planted rice and lowest in Farmer practice's (44.50 kg ha^{-1}).

The data regarding to N uptake in grain (kg ha^{-1}) there was no significant difference on N uptake in grain (kg ha^{-1}) among all the treatments. The highest N uptake (48.60 kg ha^{-1}) was recorded Z_2 (Zn-EDTA) over other treatment like Z_0 , Z_1 and Z_3 .

Data regarding to nitrogen uptake (kg ha^{-1}) showed maximum nitrogen uptake in straw (26.58 kg ha^{-1}) in SRI method as compare to other method. The minimum N uptake (26.21 kg ha^{-1}) was recorded in Farmer's practice.

Data pertaining to showed maximum N_2 uptake (27.23 kg ha^{-1}) in straw was recorded in Z_2 treatments as compare to other treatments. The minimum N uptake (25.39 kg ha^{-1}) was recorded under control.

Data pertaining to total uptake of N there was no significant variation on grain and straw. The maximum total N uptake in rice grain and straw (72.76 kg ha^{-1}) was recorded highest under SRI crop establishment method as compare to other method. The minimum total N uptake in rice grain and straw (70.74 kg ha^{-1}) was recorded under Farmer's practice.

Data regarding to showed maximum total N uptake (75.83 kg ha^{-1}) in rice grain and straw was recorded in Z_2 treatments as compare to other treatments. The minimum total N uptake (66.68 kg ha^{-1}) in rice grain and straw was recorded under Z_0 over other treatments.

4.3.2 Phosphorus content (%)

4.3.2.1 Phosphorus content in grain (%)

The phosphorus content in grain of rice as influenced by crop establishment method and application of different source of Zinc have been presented in Table 4.11

A close examination of the data revealed that the P content in the grain yield there is no significant difference among all the treatments. The maximum P content was recorded in grain (0.27%) under farmer's practice over other treatments. The minimum P content was recorded in grain (0.25%) under SRI with other treatments.

Data pertaining to maximum P content in grain (0.28%) under control with other treatments. The minimum P content was recorded in grain (0.23%) under Z₂ with other treatments.

4.3.2.2 Phosphorus content in straw (%)

Variation on phosphorus content in the straw as influenced by the method of crop establishment and different source of Zinc on rice presented in the Table 4.11.

A close examination of the data revealed that the P content in the straw there is no significant difference over all the treatments. The maximum P content was recorded in straw (0.18%) under farmer's practice with other treatments. The minimum P content was recorded in grain (0.14%) under SRI.

Data pertaining to P content the maximum P content was found in straw (0.18%) under control with other treatments. The minimum P content was recorded in straw (0.14%) under Z₂ over other treatments.

4.3.2.3 Uptake of phosphorus (kg ha⁻¹)

Data on P uptake in grain, straw and finally the total uptake with different crop establishment method and Zinc sources are presented in Table- 4.11

It is evident from the observation that maximum P uptake (13.25 kg ha⁻¹) in grain was found in SRI method as compare to other method. The minimum P content in grain was recorded in Farmer's practice.

The data regarding to P uptake there was no significant difference on P uptake in grain (kg ha⁻¹) among all the treatments. The highest P uptake (13.64 kg ha⁻¹) was recorded in Z₂ over other treatments like Z₀, Z₁ and Z₃.

Data regarding to straw showed maximum (9.45 kg ha^{-1}) P uptake by SRI method as compare to other method. The minimum P uptake (8.73 kg ha^{-1}) in straw was recorded in Farmer's practice.

Data pertaining to P uptake showed that maximum P uptake (9.49 kg ha^{-1}) in straw was recorded in Z_2 treatments as compare to other treatments. The minimum P uptake (8.39 kg ha^{-1}) in straw was recorded in Z_0 .

Further data revealed that maximum total P uptake (22.22 kg ha^{-1}) in rice grain and straw was recorded highest under SRI crop establishment method as compare to other methods. The minimum total P uptake (21.41 kg ha^{-1}) was recorded under Farmer's practice method.

Data regarding to total P uptake showed maximum total P uptake (22.46 kg ha^{-1}) was found in rice grain and straw in Z_2 treatments as compare to other treatments. The minimum total P uptake (21.21 kg ha^{-1}) in rice grain and straw was recorded under Z_0 .

4.3.3 Potassium content (%)

4.3.3.1 Potassium content in grain (%)

Variation in the K content in grain as influenced by method of crop establishment and different source of Zinc presented in the Table. 4.12

A close examination of the data revealed that the K content in the grain yield there was found no significant difference over all the treatment. The maximum K content was recorded in grain (0.29%) under farmer's practice as compare to other method. The minimum K content was recorded in grain (0.25%) under SRI.

Data pertaining to maximum K content was recorded in grain (0.29%) under control with other treatments. The minimum K content was recorded in grain (0.25%) under Z_2 over other treatments

4.3.3.2 Potassium content in straw (%)

Variation in the K content in straw as influenced by the method of crop establishment and different source of Zinc on rice presented in the Table. 4.12.

A close examination of the data revealed that the K content in the straw there was revealed no significant difference over all the treatment. The maximum K content was recorded in straw (1.62%) under farmer's practices with other treatments. The minimum K content was recorded in straw (1.52%) under SRI with other treatments.

Data pertaining to maximum K content was proved in straw (1.64%) under control with other treatments. The minimum p content was recorded in straw (1.51%) under Z_2 treatments.

4.3.3.3 Uptake of potassium (kg ha^{-1})

Data on K uptake in grain, straw and finally the total uptake with different crop establishment method and Zinc sources are presented in Table- 4.12

It was evident from the observation that maximum K uptake (13.75 kg ha^{-1}) in grain was found in farmer practice's planted rice and lowest in SRI crop establishment method of rice (13.11 kg ha^{-1}).

The data regarding to K uptake showed that there was found no significant difference on K uptake in grain (kg ha^{-1}) among all the treatment. The highest uptake (13.71 kg ha^{-1}) was recorded Z_2 (Zn-EDTA) with other treatment like Z_0 , Z_1 and Z_3 .

Data regarding straw showed maximum (91.40 kg ha^{-1}) K uptake by SRI crop establishment method as compare to other method. The minimum K uptake (87.96 kg ha^{-1}) in straw was recorded under farmer's practice.

Data pertaining to showed maximum K uptake (93.21 kg ha^{-1}) in straw was recorded in Z_2 treatment as compare to other treatments. The minimum K uptake kg ha^{-1} was recorded in straw (84.71 kg ha^{-1}) under control.

Further data revealed that maximum total K uptake ($104.51 \text{ kg ha}^{-1}$) was recorded in rice grain and straw highest under SRI crop establishment method as compare to other method. The minimum total K uptake ($101.72 \text{ kg ha}^{-1}$) was recorded under farmer's practice.

Data regarding to total K uptake ($106.91 \text{ kg ha}^{-1}$) was recorded in rice grain and straw was recorded in Z_2 treatments as compare to other treatments. The minimum total P uptake (97.60 kg ha^{-1}) in rice grain and straw was recorded in control.

4.4 Zn content (mg kg^{-1})

4.4.1 Zn content in grain (mg kg^{-1})

Variation in the Zn content in grain as influenced by method of crop establishment and different source of Zinc presented in the Table. 4.13

A close examination of the data revealed that the Zn content in the grain was found significantly higher on SRI (34.76 mg kg^{-1}) crop establishment method over other method of planting. The minimum Zn content in grain (27.86 mg kg^{-1}) was recorded under farmer's practice.

A critical observation of data reveals that Z_2 (Zn-EDTA) was recorded significantly higher Zn content in grain (35.84 mg kg^{-1}) with other treatments. The minimum Zn content in grain (24.81 mg kg^{-1}) was recorded in control with other treatments.

4.4.2 Zn content in straw (mg kg^{-1})

A critical observation of the data revealed that Zn content in straw ($125.49 \text{ mg kg}^{-1}$) was recorded significantly higher under SRI crop establishment method as compare to other method. The minimum Zn content in straw ($119.51 \text{ mg kg}^{-1}$) was recorded in farmer practice's with other method.

Data pertaining to revealed that the Zn content in straw (134.45mg kg⁻¹) was recorded significantly higher in Z₂ (Zn-EDTA) as compare to other treatments. The minimum Zn content in straw (105.70 mg kg⁻¹) was recorded under control.

4.4.3 Zn uptake in grain and straw (g ha⁻¹)

It was clear from the data pertaining to Zn uptake in grain (183.42g ha⁻¹) was recorded significantly higher under SRI as compare other method. The minimum Zn uptake in grain (134.40g ha⁻¹) was recorded under farmer's practice.

A critical observation of the data revealed that Zn uptake in grain (195.94 g ha⁻¹) was recorded significantly higher under Z₂ (Zn-EDTA) as compare to other treatments. The minimum Zn uptake in grain (107.02g ha⁻¹) was recorded under control with other treatments.

It was clear from the data Zn uptake in straw (756.62g ha⁻¹) was recorded significantly higher under SRI with other method. The minimum Zn uptake in straw (659.30g ha⁻¹) was recorded under farmer's practice

A critical observation of the data revealed that Zn uptake in straw (828.71 g ha⁻¹) was recorded significantly higher under Z₂ (Zn-EDTA) as compare to other treatments. The minimum Zn uptake in grain (550.78g ha⁻¹) was recorded under control

It was clear from the data pertaining to total Zn uptake in grain and straw (882.11g ha⁻¹) was recorded significantly higher under SRI as compare to other method. The minimum total Zn uptake in grain and straw (778.81g ha⁻¹) was recorded under farmer's practice.

A critical observation of the data reveals that total Zn uptake in grain and straw (963.16g ha⁻¹) was recorded significantly higher under Z₂ (Zn-EDTA) as compare to other treatments. The minimum total Zn uptake in grain and straw (656.48g ha⁻¹) was recorded in control.

Interaction effect of crop establishment method and different source of Zinc also produced significant increase in Zn uptake in rice grain (g ha^{-1}). Higher uptake of Zn was noticed due to application of 1.0 kg of Zn-EDTA in SRI as compare to other combination.

4.5 Effect of crop establishment method and different source of Zinc on quality parameters of rice

4.5.1 Protein content (%)

The data pertaining to protein content (%) of grain as influenced by crop establishment method and different source of Zn mentioned in Table 4.15.

The careful screening of the data revealed that there was no significant variation in the protein content of rice grain. The maximum protein content (5.92%) was noticed in SRI as compare to other method. The minimum protein (5.58%) in grain was recorded in Farmer's practice.

Data pertaining to protein content (3.06%) was recorded in straw there was no significant differences in SRI as compare to other method. The minimum protein content (2.74%) was recorded in straw under Farmer's practice.

Data pertaining to protein (3.08%) was recorded in straw there was no significant differences in Z_2 treatments as compare to other treatments. The minimum protein content (2.78%) in straw was recorded in Control.

4.5.2 Protein yield (kg ha^{-1})

The careful screening of the data revealed variation in the protein yield (kg ha^{-1}) of rice grain. The maximum protein grain yield ($290.94 \text{ kg ha}^{-1}$) was noticed in SRI as compare to other method of planting. The minimum protein grain yield ($278.13 \text{ kg ha}^{-1}$) was recorded in Farmer's practice.

The careful screening of the data revealed variation in the protein yield (kg ha^{-1}) of rice grain. The maximum protein grain yield ($303.78 \text{ kg ha}^{-1}$) was noticed in

Z₂ (Zn-EDTA) as compare to other treatments. The minimum protein grain yield (258.06.kg ha⁻¹) was recorded in control.

Data pertaining to protein in straw (166.13 kg ha⁻¹) there was no significant differences was recorded higher in SRI over other method. The minimum protein in straw (163.81 kg ha⁻¹) was recorded in Farmer's practice.

Data pertaining to protein yield (170.16 kg ha⁻¹) in straw was recorded there was no significant difference in Z₂ (Zn-EDTA) as compare to other treatments. The minimum protein (158.66 kg ha⁻¹) in straw was recorded in control.

4.5.3 Hulling (%)

Data regarding hulling (%) of grain as influenced by crop establishment method and different source of Zinc have been compiled in Table- 4.16.

Perusal of the data indicates significant effect of SRI crop establishment method on hulling (%) of rice grain. The hulling (%) was recorded significantly highest in SRI (73.78%) crop as compared to other method. The lowest hulling (%) was claimed under farmer's practice (71.47%).

Data pertaining to revealed that maximum hulling (74.35%) was recorded in Z₂ (Zn-EDTA) as compare to other treatments. The minimum hulling (70.55%) was recorded in control

4.5.4 Milling (%)

Data regarding milling (%) of grain as influenced by crop establishment method and different source of zinc have been compiled in Table 4.16.

Perusal of the data indicates that significant effect of SRI crop establishment method on milling (%) of grain. The milling (60.07%) was recorded significantly higher in SRI crop as compared to other method. The lowest milling (%) was claimed under farmer's practice (57.57%).

Data pertaining to revealed that maximum milling (60.10%) was recorded under Z₂ (Zn-EDTA) over other treatments. The minimum milling (57.21%) was recorded under control.

4.5.5 Head rice recovery (%)

Data regarding to HRR (Head rice recovery) of rice grain as influenced by crop establishment method and different source of Zinc have been compiled in Table 4.16.

Perusal of the data indicates significant effect of SRI crop establishment method on HRR (%) of grain. The HRR (50.56%) was recorded significantly higher in SRI as compared to wetland and farmer's practice. The lowest HRR (%) was claimed under farmer's practice (47.62%).

Data pertaining to revealed that maximum HRR (51.03%) was recorded in Z₂ (Zn-EDTA) over other treatments. The minimum HRR (47.04%) was recorded in control.

4.5.6 Kernel length (mm)

Data regarding to kernel length (mm) of rice grain as influenced by crop establishment method and different source of Zinc have been compiled in Table 4.16.

Perusal of the data indicates that there was no significant effect of SRI crop establishment method on kernel length (mm) of grain with other method. The kernel length (6.08 mm) was recorded higher in SRI as compare to other method. The lowest kernel length (5.14 mm) was claimed under farmer's practice.

Data pertaining to revealed that maximum kernel length (5.8 mm) was recorded in Z₂ (Zn-EDTA). The minimum kernel length (5.42mm) was recorded in control.

4.6 Economics of treatment

The value presented in the (Table 4.17) and explains the effect of treatment on the economics along with their cost, net return and benefit: cost ratio.

The cost of cultivation varied according to different crop establishment method and different sources of Zinc. The net return and benefit : cost ratio increased in SRI. The maximum net return was recorded in SRI crop establishment method followed by wetland.

Data pertaining to show that treatment combination of M_1Z_2 (SRI + Zn-EDTA) gave higher gross return ($92608.03 \text{ ` ha}^{-1}$ ), net return ( $56184.37 \text{ ` ha}^{-1}$) and also B : C ratio (1.54) followed by M_1Z_1 (SRI + $\text{ZnSO}_4.7\text{H}_2\text{O}$) and M_1Z_3 (SRI + $\text{ZnSO}_4.\text{H}_2\text{O}$). Treatment combination of M_2Z_2 (Wetland + Zn-EDTA) gave maximum Gross return ($87961.67 \text{ ` ha}^{-1}$ ), net return ( $48928.22 \text{ ` ha}^{-1}$) and also lesser B : C ratio (1.25) due to higher cost of Zn-EDTA as compare to M_2Z_1 (Wetland + $\text{ZnSO}_4.7\text{H}_2\text{O}$) the B:C ratio (1.27). Treatment combination of M_3Z_0 (Farmer practice+ Control) was recorded minimum gross return ($68417.50 \text{ ` ha}^{-1}$ ), net return ( $32963.78 \text{ ` ha}^{-1}$) and also B : C ratio(0.92) as compare other treatments.



Table 4.1: Effect of crop establishment method and different source of Zn on the plant height (cm) of rice

Treatment	Plant height (cm)			
	30 DAS	60 DAS	90 DAS	At harvest
(A) Methods of Crop Establishment				
M ₁	48.10	79.06	101.65	99.22
M ₂	45.96	75.22	99.34	97.31
M ₃	44.04	73.32	97.73	96.45
SEm±	1.93	0.73	0.56	0.68
CD (P=0.05)	NS	2.86	2.21	NS
(B) Different Source of Zinc				
Z ₀	42.92	69.83	94.78	93.96
Z ₁	47.83	77.22	101.50	98.98
Z ₂	49.33	81.46	103.69	100.09
Z ₃	44.05	74.95	98.32	97.62
SEm±	1.82	0.66	0.50	0.61
CD (P=0.05)	NS	1.96	1.50	1.81

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.2: Effect of crop establishment method and different source of Zn on the total number of tillers hill⁻¹ of rice

Treatment	Number of tillers hill ⁻¹			
	30 DAS	60 DAS	90 DAS	At harvest
(A) Methods of Crop Establishment				
M ₁	9.56	18.98	17.99	16.43
M ₂	8.68	16.72	17.22	14.63
M ₃	8.10	15.12	15.52	13.15
SEm±	0.25	0.31	0.29	0.60
CD (P=0.05)	0.98	1.21	1.15	2.34
(B) Different Source of Zinc				
Z ₀	7.19	13.71	14.13	12.32
Z ₁	9.28	17.81	17.96	15.74
Z ₂	10.38	20.09	18.74	16.87
Z ₃	8.27	16.14	16.81	14.01
SEm±	0.23	0.29	0.24	0.51
CD (P=0.05)	0.67	0.85	0.71	1.50

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.3: Effect of crop establishment method and different source of Zn on the number of total green leaves hill⁻¹

Treatment	Green leaves hill ⁻¹			
	30 DAS	60 DAS	90 DAS	At harvest
(A) Methods of Crop Establishment				
M ₁	30.49	63.04	59.75	48.61
M ₂	27.94	59.57	56.92	46.45
M ₃	27.03	53.72	51.75	41.76
SEm±	0.61	1.22	1.06	1.27
CD (P=0.05)	2.39	4.80	4.17	4.97
(B) Different Source of Zinc				
Z ₀	24.98	49.11	51.11	38.38
Z ₁	29.13	61.86	56.67	48.12
Z ₂	31.37	67.48	62.11	52.69
Z ₃	28.47	56.67	54.67	43.24
SEm±	0.57	0.93	0.93	1.22
CD (P=0.05)	1.70	2.76	2.76	3.62

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.4 : Effect of crop establishment method and different source of Zn on dry matter accumulation (g hill⁻¹) of rice.

Treatment	Dry matter (hill ⁻¹)			
	30 DAS	60 DAS	90 DAS	At harvest
(A) Methods of Crop Establishment				
M ₁	5.79	30.08	65.49	91.73
M ₂	5.29	27.47	60.68	88.71
M ₃	4.87	26.42	57.55	84.81
SEm±	0.17	0.47	1.22	1.09
CD (P=0.05)	0.66	1.83	4.79	4.29
(B) Different Source of Zinc				
Z ₀	4.67	24.34	53.04	80.22
Z ₁	5.79	29.38	65.87	90.86
Z ₂	5.87	31.06	67.51	94.87
Z ₃	4.94	27.18	58.52	87.71
SEm±	0.15	0.27	1.18	0.54
CD (P=0.05)	0.43	0.80	3.49	1.62

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.5: Effect of crop establishment method and different source of Zn on LAI of rice.

Treatment	LAI		
	30 DAS	60 DAS	90 DAS
(A) Methods of Crop Establishment			
M ₁	1.69	3.48	2.46
M ₂	1.45	2.89	2.42
M ₃	1.43	2.50	2.37
SEm±	0.05	0.16	0.14
CD (P=0.05)	0.19	0.63	NS
(B) Different Source of Zinc			
Z ₀	1.32	2.43	2.32
Z ₁	1.63	2.89	2.46
Z ₂	1.78	3.62	2.51
Z ₃	1.35	2.87	2.38
SEm±	0.03	0.14	0.10
CD (P=0.05)	0.09	0.41	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.6: Effect of crop establishment method and different source of Zn on the chlorophyll

Treatment	Chlorophyll content		
	30 DAS	60 DAS	90 DAS
(A) Method of Crop Establishment			
M ₁	30.74	30.67	27.50
M ₂	27.96	30.54	25.79
M ₃	25.58	29.95	24.40
SEm±	1.21	0.99	0.96
CD (P=0.05)	NS	NS	NS
(B) Different Source of Zinc			
Z ₀	26.25	28.39	24.00
Z ₁	28.47	30.82	26.64
Z ₂	29.90	32.44	27.00
Z ₃	27.75	29.89	25.94
SEm±	1.11	0.96	0.93
CD (P=0.05)	NS	NS	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.7: Effect of crop establishment method and different source of Zn on yield attributing characters of rice.

Treatment	No. of panicle plant ⁻¹	Panicle length (cm)	Panicle weight (g)
(A) Method of Crop Establishment			
M ₁	15.02	26.81	4.83
M ₂	13.24	24.85	4.66
M ₃	11.13	24.12	4.38
SEm±	0.70	0.38	0.09
CD (P=0.05)	2.75	1.50	0.34
(B) Different Source of Zinc			
Z ₀	10.19	22.74	4.20
Z ₁	14.27	25.76	4.76
Z ₂	15.53	28.19	4.97
Z ₃	12.53	24.37	4.56
SEm±	0.69	0.34	0.08
CD (P=0.05)	2.05	1.02	0.24

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4. 8: Effect of crop establishment method and different source of Zn on yield attributing characters of rice

Treatment	Filled grain plant ⁻¹	Sterility (%)	Test weight (g)
(A) Method of Crop Establishment			
M ₁	218.92	7.71	22.75
M ₂	212.25	9.41	21.28
M ₃	200.13	11.40	21.05
SEm±	1.32	1.02	0.69
CD (P=0.05)	5.20	NS	NS
(B) Different Source of Zinc			
Z ₀	182.06	12.13	20.61
Z ₁	219.11	8.63	21.84
Z ₂	239.56	7.36	23.25
Z ₃	201.00	9.90	21.07
SEm±	0.82	0.82	0.66
CD (P=0.05)	2.43	2.44	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.9: Effect of crop establishment method and different source of Zn on grain yield (q ha⁻¹), straw yield (q ha⁻¹) and harvest index (%) of rice

Treatment	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Harvest index (%)
(A) Method of Crop Establishment			
M ₁	51.95	60.96	46.42
M ₂	49.53	56.73	46.41
M ₃	47.67	54.83	46.33
SEm±	0.32	0.78	0.40
CD (P=0.05)	1.25	3.04	NS
(B) Different Source of Zinc			
Z ₀	44.04	52.04	45.84
Z ₁	51.92	59.17	46.72
Z ₂	54.31	61.56	47.10
Z ₃	48.59	57.26	45.88
SEm±	0.26	0.65	0.35
CD (P=0.05)	0.77	1.94	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.10: Effect of crop establishment method and different source of Zn on N concentration and N uptake (kg ha⁻¹) of rice.

Treatment	N Content (%)		N Uptake (kg ha ⁻¹)		Total N uptake (kg ha ⁻¹)
	Grain	Straw	Grain	Straw	
(A) Method of Crop Establishment					
M ₁	0.89	0.44	46.55	26.58	72.76
M ₂	0.90	0.46	44.98	26.24	71.56
M ₃	0.95	0.49	44.50	26.21	70.74
SEm±	0.05	0.02	2.48	0.88	2.50
CD (P=0.05)	NS	NS	NS	NS	NS
(B) Different Source of Zinc					
Z ₀	0.94	0.49	41.29	25.39	66.68
Z ₁	0.90	0.45	46.51	26.60	73.11
Z ₂	0.89	0.44	48.60	27.23	75.83
Z ₃	0.93	0.46	44.97	26.16	71.13
SEm±	0.05	0.02	2.44	1.08	2.42
CD (P=0.05)	NS	NS	NS	NS	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄·7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄·H₂O.

Table 4.11: Effect of crop establishment method and different source of Zn on P concentration (%) and P uptake (kg ha⁻¹) of rice.

Treatment	P Content (%)		P Uptake (kg ha ⁻¹)		Total P uptake (kg ha ⁻¹)
	Grain	Straw	Grain	Straw	
(A) Methods of Crop Establishment					
M ₁	0.25	0.14	13.25	9.45	22.22
M ₂	0.26	0.15	12.79	8.82	21.98
M ₃	0.27	0.18	12.58	8.73	21.41
SEm±	0.03	0.01	1.43	0.50	0.96
CD (P=0.05)	NS	NS	NS	NS	NS
(B) Different Source of Zinc					
Z ₀	0.28	0.18	12.16	8.39	21.21
Z ₁	0.26	0.15	12.88	9.39	22.37
Z ₂	0.23	0.14	13.64	9.49	22.46
Z ₃	0.27	0.17	12.82	9.28	21.44
SEm±	0.03	0.01	1.45	0.65	1.42
CD (P=0.05)	NS	NS	NS	NS	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.12: Effect of crop establishment method and different source of Zn on K concentration (%) and K uptake (kg ha⁻¹) of rice.

Treatment	K Content (%)		K Uptake (kg ha ⁻¹)		Total K uptake (kg ha ⁻¹)
	Grain	Straw	Grain	Straw	
(A) Method of Crop Establishment					
M ₁	0.25	1.52	13.11	91.40	104.51
M ₂	0.27	1.56	13.23	89.72	102.94
M ₃	0.29	1.62	13.75	87.96	101.72
SEm±	0.02	0.11	0.72	5.50	6.05
CD (P=0.05)	NS	NS	NS	NS	NS
(B) Different Source of Zinc					
Z ₀	0.29	1.64	12.89	84.71	97.60
Z ₁	0.26	1.54	13.52	91.52	105.04
Z ₂	0.25	1.51	13.71	93.21	106.91
Z ₃	0.28	1.57	13.33	89.33	102.66
SEm±	0.02	0.08	0.73	4.83	4.81
CD (P=0.05)	NS	NS	NS	NS	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.13: Effect of crop establishment method and different source of Zn on the Zn concentration (mg kg⁻¹) and Zn uptake (g ha⁻¹) of rice.

Treatment	Zn Content (mg kg ⁻¹)		Zn Uptake (g ha ⁻¹)		Total uptake Zn grain and straw (g ha ⁻¹)
	Grain	Straw	Grain	Straw	
(A) Method of Crop Establishment					
M ₁	34.76	125.49	183.42	756.62	882.11
M ₂	29.22	120.59	146.15	699.61	820.20
M ₃	27.86	119.51	134.40	659.30	778.81
SEm±	1.15	1.16	7.09	12.68	13.38
CD (P=0.05)	4.50	4.54	27.84	49.78	52.54
(B) Different Source of Zinc					
Z ₀	24.21	105.70	107.02	550.78	656.48
Z ₁	31.88	125.03	166.26	740.67	865.69
Z ₂	35.84	134.45	195.94	828.71	963.16
Z ₃	30.53	122.28	149.42	700.55	822.83
SEm±	1.09	1.12	5.57	10.23	10.91
CD (P=0.05)	3.24	3.32	16.56	30.39	32.42

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.14: Interaction effect between crop establishment method and different source of Zinc on Zinc uptake (g/ha⁻¹) in grain of rice.

Treatment	Z₀	Z₁	Z₂	Z₃
M ₁	111.312	203.9714	233.3783	185.0111
M ₂	116.82	151.39	189.24	127.15
M ₃	92.91	143.42	165.18	136.09
			SEm±	CD (0.05)
For Method of crop establishment			7.09	27.84
For different source of Zn			5.57	16.56
Different source of Zn at same level of			9.65	13.65
Method of Crop establishment				
Method of crop establishment at			9.65	28.68
Same level of different source of Zn				

Table 4.15: Effect of crop establishment method and different source of Zn on the Protein content (%) and uptake (kg ha⁻¹) of rice

Treatment	Protein (%) in Grain	Protein (%) in Straw	Protein yield (kg ha ⁻¹)	Protein yield in grain and straw (kg ha ⁻¹)
(A) Method of Crop Establishment				
M ₁	5.92	2.74	290.94	166.13
M ₂	5.61	2.84	281.13	164.00
M ₃	5.58	3.06	278.13	163.81
SEm±	0.33	0.13	15.49	5.49
CD (P=0.05)	NS	NS	NS	NS
(B) Different source of Zinc				
Z ₀	5.58	3.08	258.06	158.66
Z ₁	5.78	2.81	290.67	166.27
Z ₂	5.86	2.78	303.78	170.16
Z ₃	5.59	2.87	281.08	163.48
SEm±	0.33	0.13	15.27	6.74
CD (P=0.05)	NS	NS	NS	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.16: Effect of crop establishment method and different source of Zn on different quality parameter of rice.

Treatment	Hulling (%)	Milling (%)	Head Rice Recovery (HRR%)	Kernel length (mm)
(A) Method of Crop Establishment				
M ₁	73.38	60.07	50.56	6.08
M ₂	71.96	58.26	47.95	5.48
M ₃	71.47	57.57	47.62	5.14
SEm±	0.17	0.28	0.50	0.36
CD (P=0.05)	0.67	1.12	1.95	NS
(B) Different Source of Zinc				
Z ₀	70.55	57.21	47.05	5.42
Z ₁	72.59	58.88	48.83	5.55
Z ₂	74.35	60.10	51.03	5.80
Z ₃	71.58	58.33	47.93	5.49
SEm±	0.17	0.28	0.65	0.36
CD (P=0.05)	0.51	0.82	1.94	NS

M₁: System of Rice Intensification (SRI); M₂: Wet land; M₃: Farmer's Practice;
Z₀: Control; Z₁: ZnSO₄.7H₂O; Z₂: Zn-EDTA; Z₃: ZnSO₄.H₂O.

Table 4.17: Economics of treatment combinations

S. No.	Treatment	Total cost of cultivation (` ha <sup>-1</sup>)	Gross return (` ha ⁻¹)	Net return (` ha ⁻¹)	B:C ratio
1.	M ₁ Z ₀	30983.66	75664.17	44680.51	1.44
2	M ₁ Z ₁	34583.66	87467.08	52883.42	1.52
3	M ₁ Z ₂	36423.66	92608.03	56184.37	1.54
4	M ₁ Z ₃	33683.54	83697.43	50013.89	1.48
5	M ₂ Z ₀	33593.66	72664.33	39070.67	1.16
6.	M ₂ Z ₁	37193.45	84784.17	47590.72	1.27
7.	M ₂ Z ₂	39033.45	87961.67	48928.22	1.25
8.	M ₂ Z ₃	36293.66	78805.83	42512.17	1.17
9.	M ₃ Z ₀	35453.72	68417.50	32963.78	0.92
10.	M ₃ Z ₁	39053.72	81610.00	42556.28	1.08
11.	M ₃ Z ₂	40893.24	84733.33	43840.09	1.07
12.	M ₃ Z ₃	38153.72	76516.67	38362.95	1.0

Sale price of rice grain = ` 13.45 kg<sup>-1</sup>, Sale price of rice straw = ` 2.50 kg⁻¹

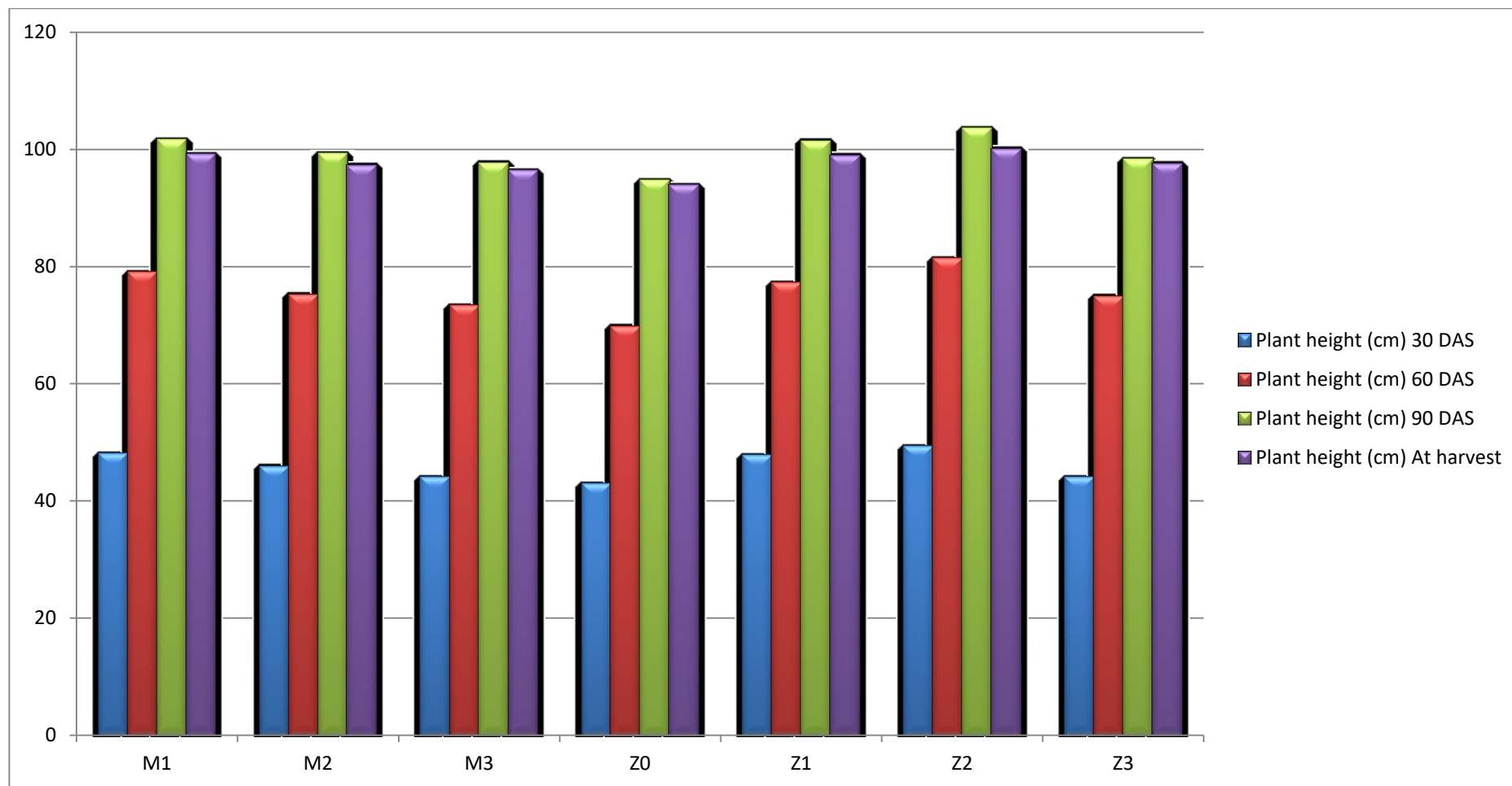


Figure 4.1: Effect of crop establishment method and different source of Zn on the plant height (cm) of rice.

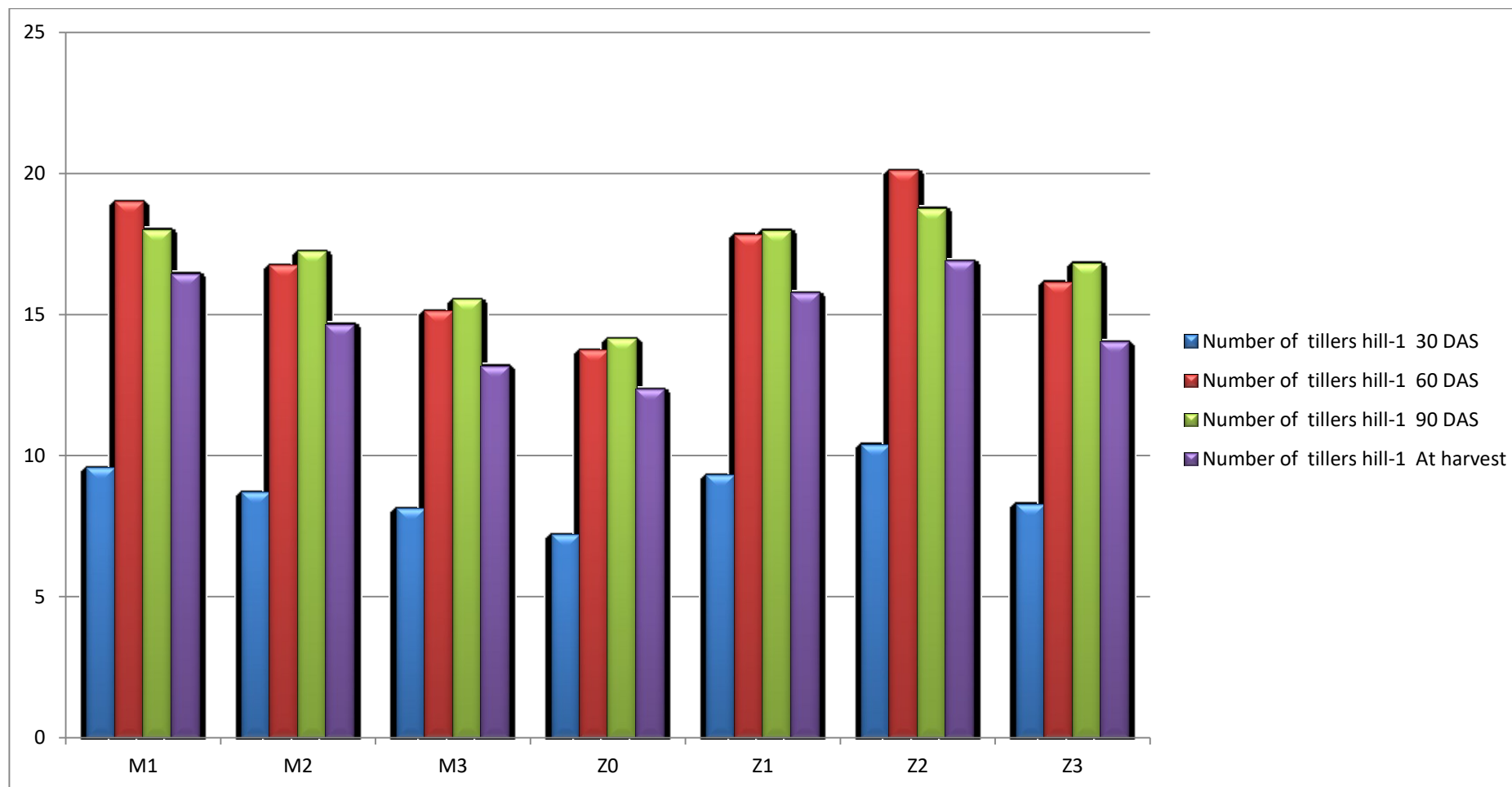


Figure 4.2: Effect of crop establishment method and different source of Zn on the total number of tillers hill⁻¹ of rice.

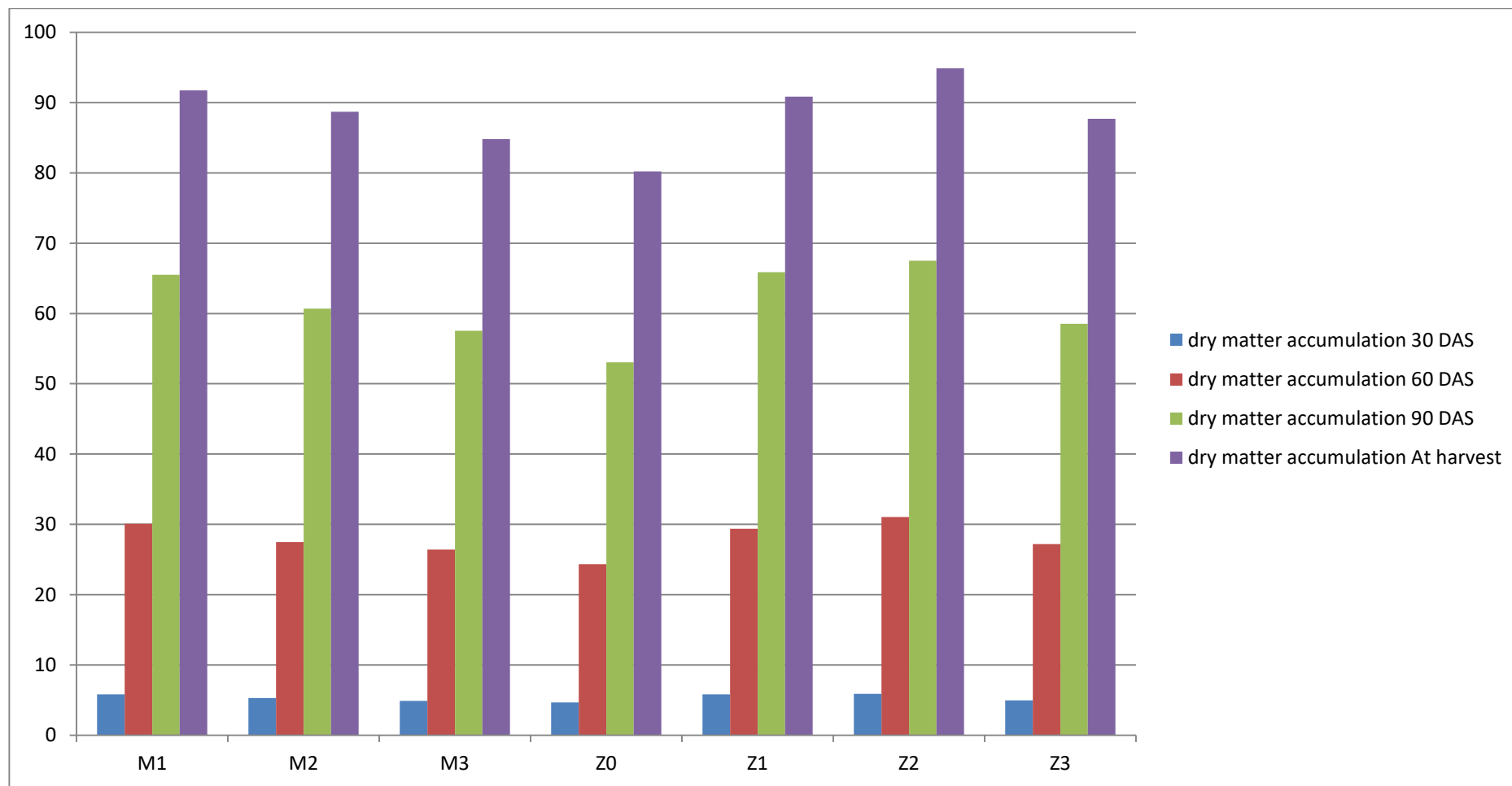


Figure 4.3: Effect of crop establishment method and different source of Zn on dry matter accumulation hill⁻¹ of rice.

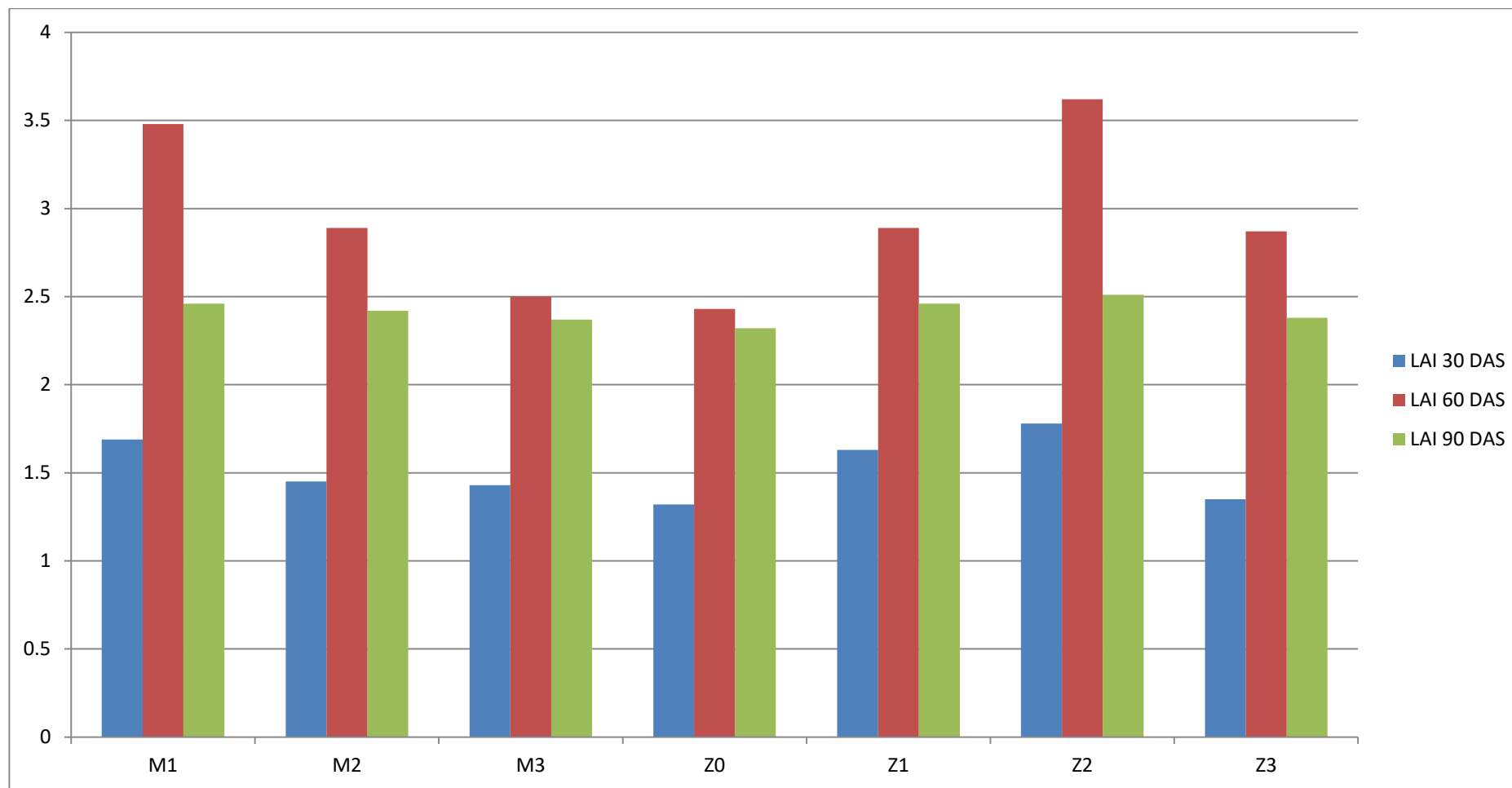


Figure 4.4: Effect of crop establishment method and different source of Zn on LAI of rice.

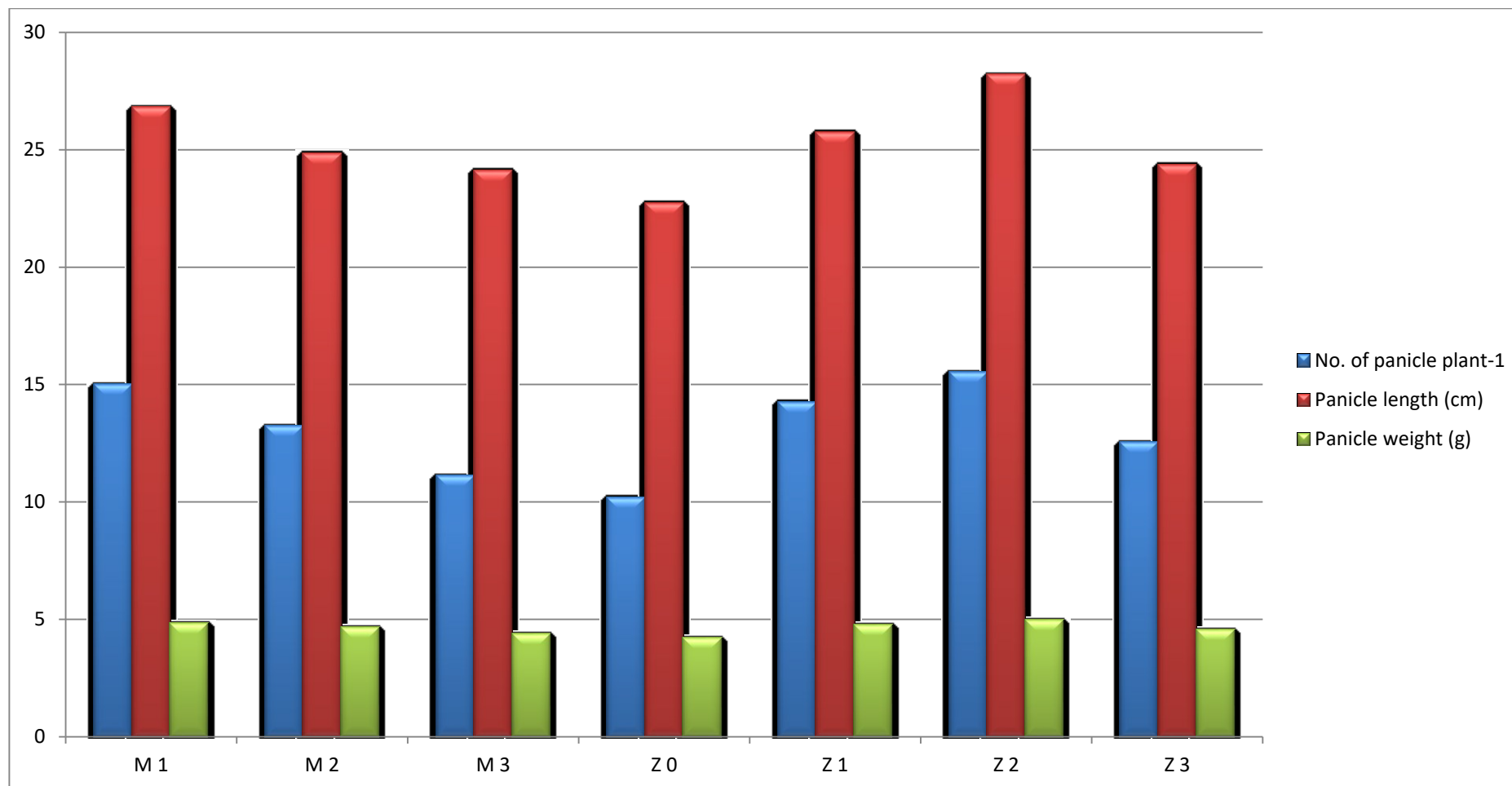


Figure 4.5: Effect of crop establishment method and different source of Zn on yield attributing characters of rice.

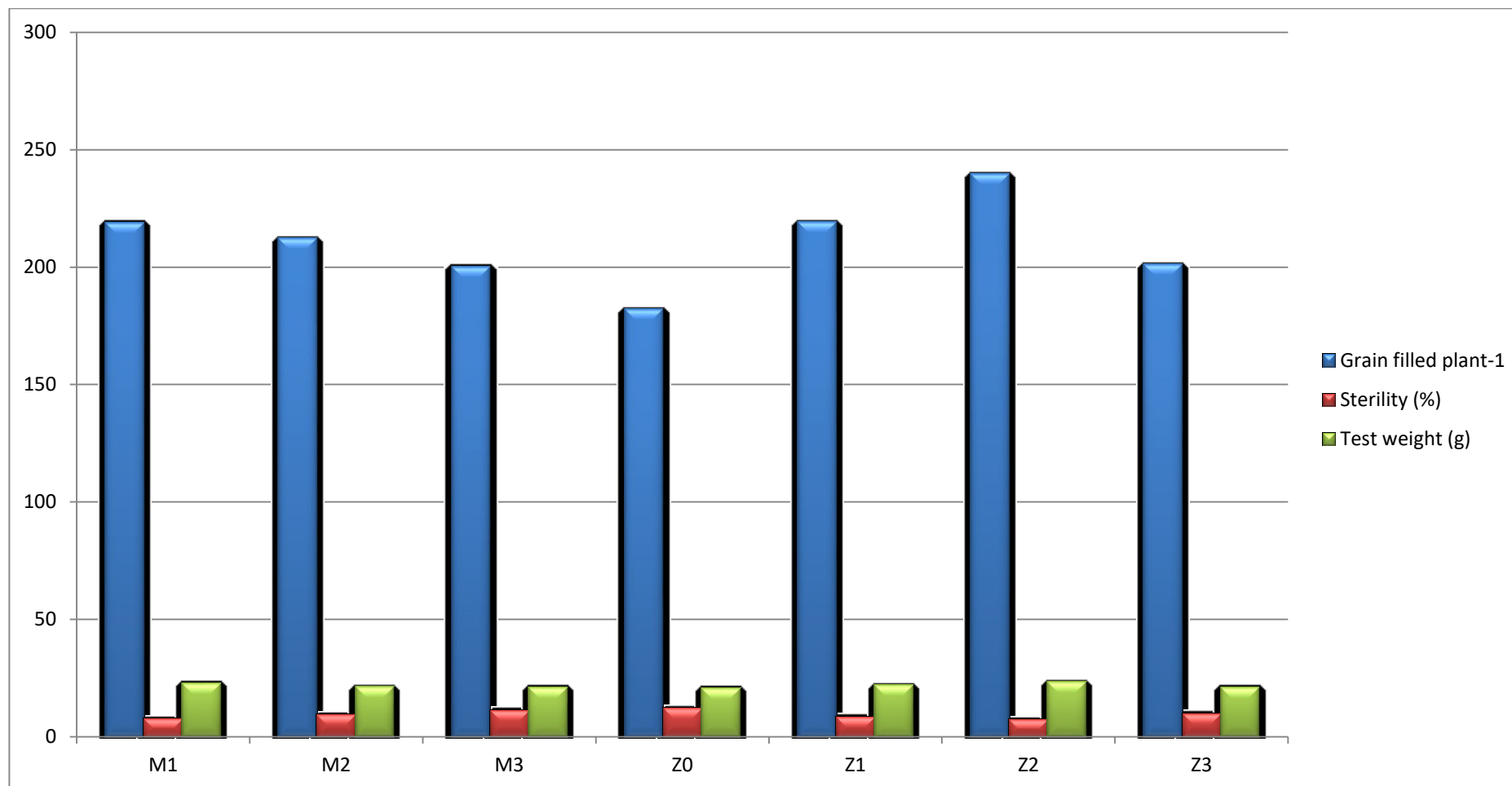


Figure 4.6: Effect of crop establishment method and different source of Zn on yield attributing characters of rice.

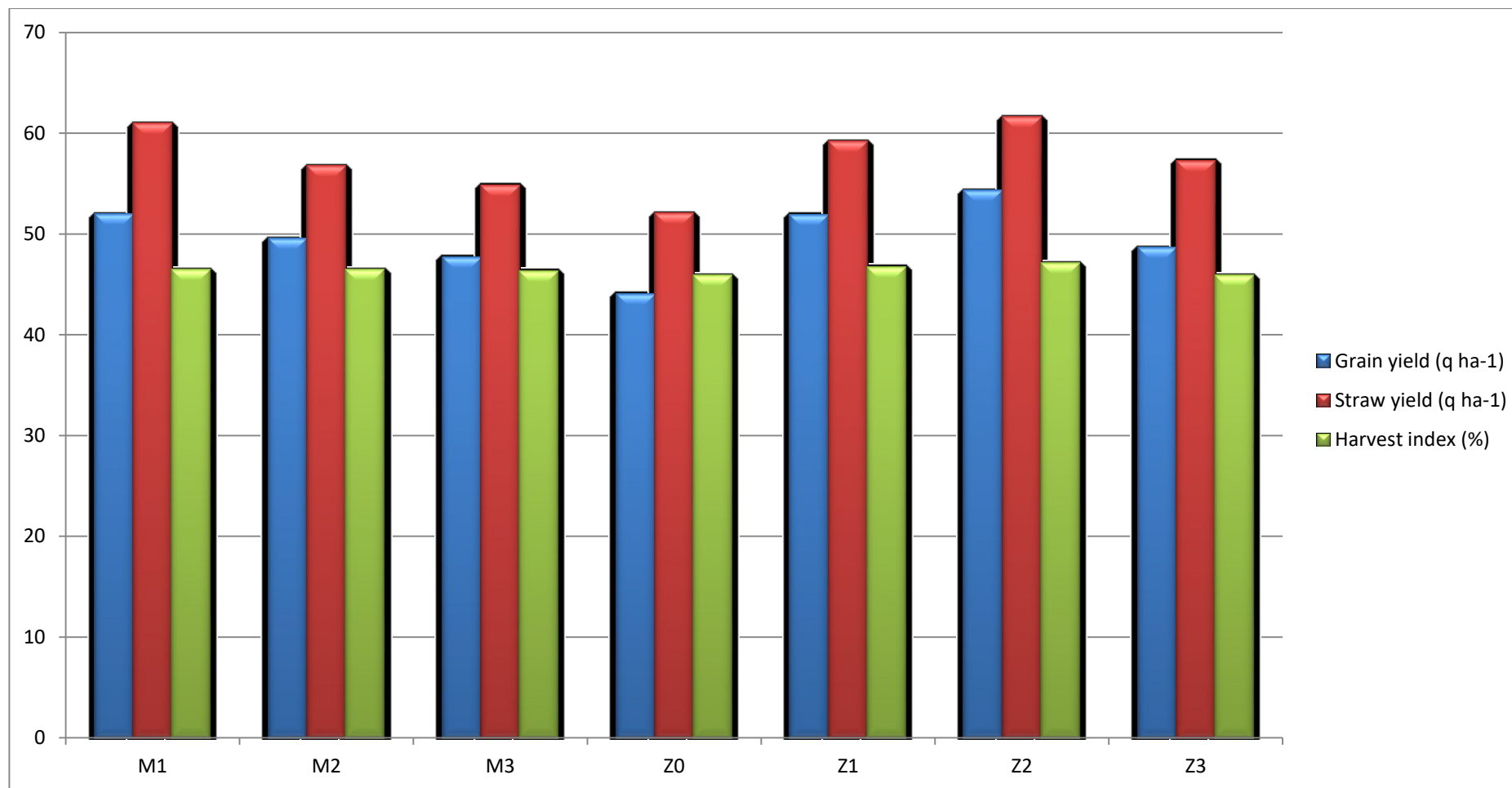


Figure 4.7: Effect of crop establishment method and different source of Zn on grain yield (q ha⁻¹) , straw yield (q ha⁻¹) and harvest index (%) of rice.

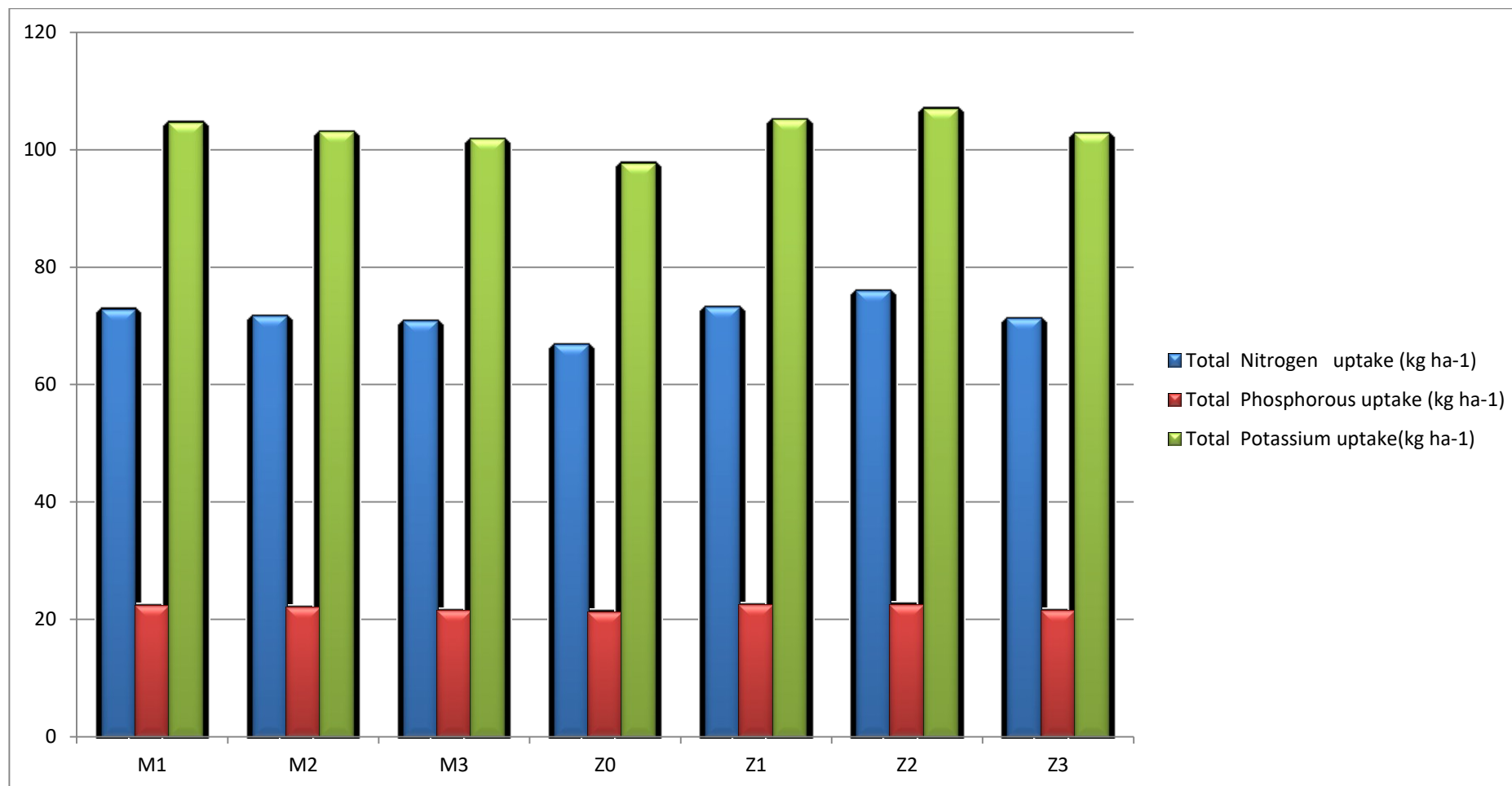


Figure 4.8: Effect of crop establishment method and different source of Zn on total uptake of NPK (kg ha⁻¹) of rice.

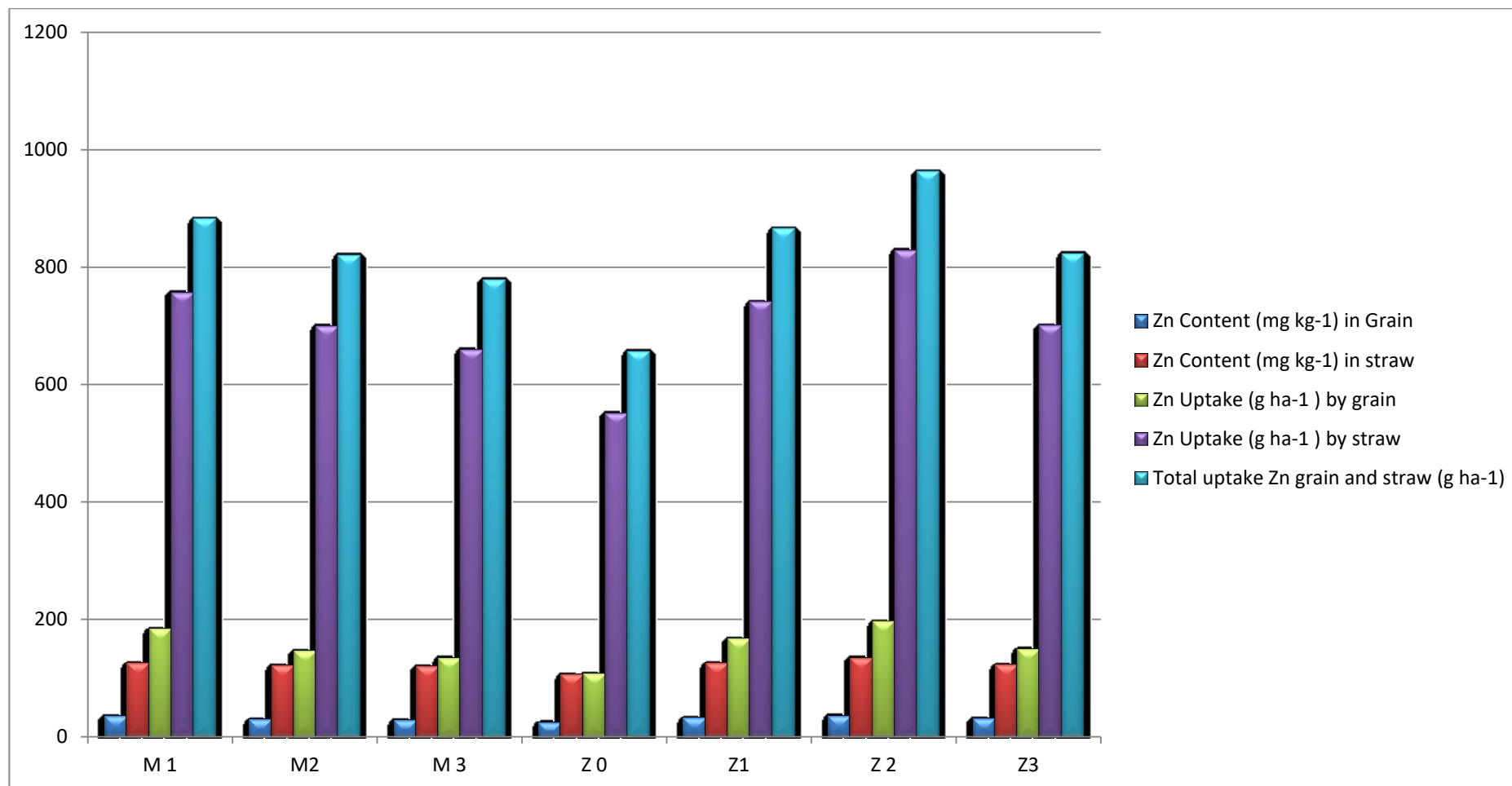


Figure 4.9: Effect of crop establishment method and different source of Zn on Zn content (mg kg⁻¹) and total Zn uptake (g ha⁻¹) of rice.

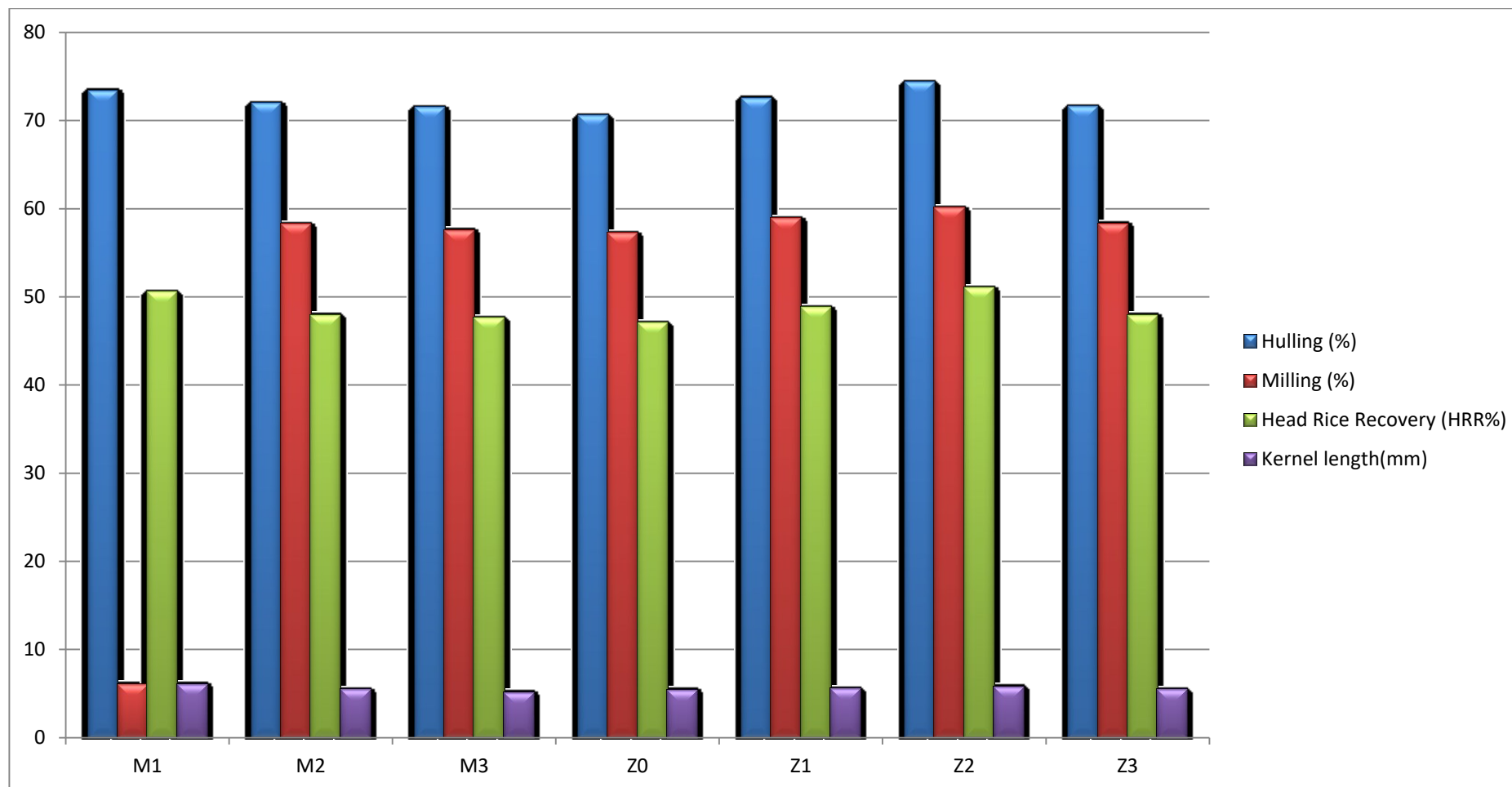


Figure 4.10: Effect of crop establishment method and different source of Zn on different quality parameter of rice.

DISCUSSION

In this chapter an attempt has been made to describe the possible reasons for the variability obtained due to treatment differences on the basis of findings described in preceding chapter. The result obtained is being discussed here in light of general principle of agronomy and established findings to procure sound clarification of the aims. The results have been duly supported by references available in the literature as and where necessary.

5.1 Effect of weather conditions on growth and yield of rice

The effect of weather conditions during the crop season is one of the most important factors which determine the extent of crop growth, development and its overall performance. The weather conditions have greater significance for a crop like rice which requires high temperature, humidity and precipitation during the vegetative phase and more sun-shine duration during the reproductive phase for higher yield. A slight deviation from the normal range in weather condition may adversely affect the crop growth and ultimately the yield. The meteorological data as well as regular field observations show that crop remained almost unaffected by weather variations except a few spells of short term drought at later stage of the crop. Whenever moisture stress occurred irrigation was provided to check the moisture stress. However, in general, good precipitation was recorded from July to September for the normal growth of rice.

As such the weather conditions were satisfactory which favoured proper growth and development and finally the good yield of rice.

5.2 Effect of crop establishment method on growth and yield of rice

5.2.1 Growth parameters

The effect of different planting method of crop establishment implied in rice, on the growth characters have been studied in the present investigation. The growth parameters *viz.* plant height, number of tillers, leaf area index and plant dry matter were markedly influence by various planting method applied in rice.

Maximum values of these parameters were recorded with system of rice intensification of rice closely followed by wetland transplanting than farmer's practices. This is particularly planting has significant effect in rice cultivation. It facilitates good transplanting, availability of nutrient, ensure better seedling establishment, kills weed and helps plant to grow vigorously. Early establishment and subsequent growth of transplanted seedling in were faster as reflected in taller plants (Table-4.1), more number of tillers per hill (Table-4.2) and plant dry matter production per plant (Table-4.4). These results are in conformity with finding of Singh *et al.* (2005). The panicle length and number of grain/panicle in transplanted rice were significantly higher than other planting method. It may be attributed due to higher availability of nutrients in submerged field as compared to waterlogged conditions.

5.2.2 Yield and yield attributes

The finding of the present investigation indicated profound effect of different crop establishment method of rice on yield and yield attributes (Table -4.8). It was noted that different planting method had significantly increased the number of productive tillers hill⁻¹, grain panicle⁻¹. Relatively better performance of all yield attributes were noted in transplanting.

With regard to the establishment method, the wetland transplanting method recorded slightly higher number of effective tillers m⁻² which was at par with method. The possible reason for this is that at closer spacing, the production of tillers might be

more per unit area having more plants/ha. Similar results were reported by Dixit *et al.* (2007). However, longer and heavier panicles along with more number of grains were recorded with technique which was statistically at par with wetland technique. No significant difference was observed in the test weight of paddy obtained by technique or conventional practice. This is in conformity with the results of Latif *et al.* (2004).

Previously study showed that rice plant grown with Wetland transplanting and SRI method had higher root growth in first 20 cm in comparison to those in. Most root growth was observed superficial with plant cultivated with conventional method. However the root growth in wetland transplanting and SRA plant began to be offset by the plant at a depth of 20-30 cm. Furthermore, root growth was noticed with plant at lower depths, below 30 cm. this greater root growth to lower depths suggested that plant cultivated with method which include alternate drying and draining of the soil were capable of developing greater root penetration in comparison to SRI and Wetland transplanting. Barison(2002).

5.2.3 Effect on nutrient uptake

SRI transplanting of rice recorded maximum uptake of nitrogen, phosphorus and potassium followed by wetland transplanting and farmer's practice, being at par to each other. Rice grown under method obtained higher grain and straw yield, resulting in to higher NPK uptake compared with others.

To get the clearer picture of nutrient uptake constraint on yield, one should to compare grain yield with nutrient content concentration difference between SRI and wetland transplanting method. As we have seen , grain yield average 51.95 qha⁻¹ under SRI while that of Farmer practice's was 47.67 qha⁻¹ an increase of 90% grain yield , reflected in the increased N and K content and concentration in the rice plant and grain. It could be possible that the increase of grain yield with compared to that of wetland transplanted was due to farmers allocating their best sites to or to application of difference source of Zn to plot. Result from our soil analysis, however, showed that and wetland transplanted plots had similar fertility as commonly evaluated.

5.2.4 Economics

Acceptation of any advanced agro-technique by the farmers directly depends on economic status of the farmer and economic feasibility of the technique. Therefore it is essential to analyze the results from the economic point of view. The cost of cultivation, gross return, net return and output input were worked out and the data are presented in Table (4.17).

Among different crop establishment method and different sources of Zinc application M_1Z_2 (SRI + Zn-EDTA) gave highest gross return (92608.03 ` ha<sup>-1</sup>), net return (56184.37 ` ha⁻¹) and also B:C ratio (1.54) followed by M_1Z_1 (SRI + ZnSO₄.7H₂O), and M_1Z_3 (SRI+Zn-SO₄.H₂O). Treatment combination of M_3Z_0 (Farmer practice+ Control) was recorded minimum gross return (68417.50 ` ha<sup>-1</sup>), net return (32963.78 ` ha⁻¹) and also B:C ratio (0.92) over other treatment.

5.3 Effect of difference sources of Zinc on growth and growth attributes

5.3.1 Growth parameter

All the growth attributes were affected by various treatments at different stages of growth (30, 60, 90 DAT and at harvest). Perusal of the data revealed marked variation on growth attributes viz. plant height, tiller number hill⁻¹, fresh weight, dry weight, number of leaves hill⁻¹, leaf area hill⁻¹, LAI and chlorophyll content due to different levels of zinc (Zn). Zinc is the most important trace element which is absorbed by rice in enough quantity to complete its life cycle (Sommer and Lipman, 1926 and Arnon and Stout, 1939). The role of zinc has long been recognized to have a stimulating effect on rice causing significant increase in the number of productive tillers, dry matter production and leaf area index with every increase in the levels of zinc sulphate (Grewal *et al.*, 1997).

Increase in number of tillers due to micronutrient application can be discussed in light of the fact that more photosynthates produced was made available for initiation of tiller and their growth under these treatments were duly supported by

more number of green leaves (Verma and Neue, 1984). Zinc nutrition is known to increase tillering in rice, which caused a significant increase in dry matter production (Ghatak *et al.*, 2005). Slaton *et al.* (2005) also observed an increase in dry matter accumulation of rice by application of Zn. Application of Zn, from Zn-coated urea and other sources is reported to have beneficial effect on LAI (Grewal *et al.*, 1997). Similar findings were reported by Kulandaivel *et al.*, also in 2004.

Low Zn content in grain (Graham and Welch 1996; Cakmak *et al.* 1999) can be attributed to dilution of Zn in plant tissue because of enhanced dry matter production (Rengel and Graham, 1995). Zinc application @ 25-30 kg ha⁻¹ was sufficient to correct Zn deficiency for 4-7 years and the residual effect was best with soil application on long range basis. It has also been observed that after a certain limit in micronutrient fertilization further increase in fertilizer application caused not only reduction in yield but also decreased micronutrient grain density (Nambiar and Motiramani (1983). Among the different Zn fertilizer sources, residual effect of Zn-EDTA was found to be the best with respect to growth, yield attributes, grain, straw, Zn content and uptake and economics (Singh and shivay, 2013).

5.3.2 Yield and yield attributes

The maximum grain and straw yield was due to marked improvement in dry matter accumulation. Grain yield of rice can only be improved to a degree by increasing grain size. This is because the growth is restricted by the size of hulls (Yoshida, 1972).. Among the difference sources of Zn, Zn-EDTA 1 kg ha⁻¹ registered maximum yield attributes like, number of panicles/ m², panicle weight, panicle length, number of spikelets (grains) / panicle, grain filling percent, and test weight. The response of the yield attributes to different zinc sources was in the order of Z₂>Z₁>Z₃>Z₀. The yield attributing characters with slight improvement might be due to the crop genotype which does not change with the above said agronomic management practices (Kulandaivel *et al.*, 2004

Dravid and Goswami (1987) reported significant increase in the number of panicles per square metre, more number of grains per panicle and increased panicle

weight with the increase in the levels of zinc sulphate which were further confirmed by Ahamed *et al.* (1992); Devarajan and Krishnasamy (1996). Rengel and Graham (1995) also reported an appreciable improvement in the rice yield attributes like panicle length, fertility percentage and test weight due to increase in the levels of zinc sulphate. Tripathi and Tripathi (2004) found that application of 30 kg ZnSO₄ ha⁻¹ resulted in significantly higher grain and straw yields, harvest index, seed weight per panicle and 1000-seed weight.

5.3.3 Effect of different sources of Zinc on grain and straw yield of rice

The grain and straw yield (Table 4.9) of rice were increased considerably by application of different sources of Zinc over the control. Application of Zn-EDTA @ 1.0 kg ha⁻¹ (as ½ basal and as ½ foliar) in the rice increased the tiller number, dry matter production and yield components which eventually resulted higher grain yield (54.31 q/ha) and straw yield (61.56 q/ha). The minimum grain yield (44.04 q/ha) and straw yield (52.04) was recorded under control with other treatment. Zinc application invariably enhanced translocation of photosynthates which was responsible for realization of higher grain and straw yields (Kulandaivel *et al.*, 2004).

Chelated zinc showed high solubility and stability of Zn and increased the movement of Zn ions in to the plants to increase the grain yield, (Sahu *et al.*, 1994). The favourable influence of applied Zn on yield may be due to its catalytic or stimulatory effect on most of the physiological and metabolic process of plants (Mandal *et al.*, 2009). Singh *et al.* (1987) advocated that rice grain and straw yields could be increased progressively with the increase in the level from 10 to 30 kg ZnSO₄ ha⁻¹.

5.3.4 Effect of different sources of zinc on quality of rice

The quality parameters depend upon a number of factors such as variety, shape, size, and chalkiness of endosperm, nature of post harvest handling and inherent strength of grain to resist breakage and damage. Adequate supply of nutrients along with micronutrients might have resulted in strengthening of grain to

resist breakage (Govindaswami and Murthy, 1966; and Govindaswamy, 1967). The perusal of data clearly showed that application of zinc @ 10 kg ha⁻¹ registered maximum values in hulling, milling, head rice recovery (%), kernel length (mm), kernel breadth (mm), kernel length after cooking, volume expansion ratio, water uptake (ml), amylose content (%), alkali value, protein content, and protein yield, which remained significantly superior to other doses. The response of quality parameters to different zinc sources was in the order of $Z_2 > Z_1 > Z_3 > Z_0$. Application of zinc might be due to increased vigour, photosynthetic accumulation and better translocation of photosynthates to the sink (Kanda and Dixit, 1995)

In addition, Zn is critical to the control of gene transcription and the coordination of other biological processes regulated by proteins containing DNA-binding Zn-finger motifs (Rhodes and Klug 1993). Jat *et al.* (2011) observed that cooking quality of rice could be significantly improved by legume residue incorporation along with application of Zn-enriched urea. The N and Zn fertilization is directly responsible for higher 1,000-grain weight because N increased the crude protein content in grains (Naik and Das, 2008).

The data further revealed that hulling, milling, head rice recovery (%), kernel length (mm), kernel breadth (mm), kernel length after cooking, volume expansion ratio, water uptake (ml), amylose content (%), alkali value, protein content, and protein yield were significantly increased by the application of different sources of Zinc

5.3.5 Effect of zinc on nutrients content and its removals by rice

The uptake of nutrient by a crop depends upon the total biomass production and nutrient concentration in plant parts which in turn is influenced by soil climate, cultural practices, levels of nutrients applied and age of the plant (Gupta and O'Toole, 1986). (Masuda *et al.*, 2008).

Jat *et al.* (2011) found that application of 2% Zn-enriched urea ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) was the best in terms of Zn concentrations in grain and straw of aromatic hybrid rice,

2% Zn-enriched urea ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) recorded higher Zn concentrations in grain as well as in straw of aromatic hybrid rice. Leaf Zn content ranged from 5.5 ppm in the control to 13.4 ppm with zinc sulphate application. Grain yield was significantly correlated with leaf Zn content (Subbaiah *et al.*, 1994). Results suggested that benefits of Fe application to rice in sodic soils could only be realised if it was applied along with Zn (Swarup 1993).

5.4 Economics

Adoption of any technology in modern agriculture can only be feasible and acceptable to farmers, if it is economically viable. Economic viability is a function of gain or loss. Any practice or methodology in order to be economically viable must have a substantial balance over its cost. In order to assure the profitability of treatments (different crop establishment methods and different sources of Zinc) net return and benefit cost ratio were worked out. Among the different Zinc Sources, Zn-EDTA 1kg ha^{-1} treatment combination with M_1Z_2 (SRI + Zn-EDTA) gave higher gross return ($92608.03 \text{ ` ha}^{-1}$ ), net return ( $56184.37 \text{ ` ha}^{-1}$) and also B:C ratio (1.54) followed by M_1Z_1 (SRI + $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$), and M_1Z_3 (SRI + $\text{Zn-SO}_4 \cdot \text{H}_2\text{O}$). Treatment combination of M_2Z_2 (Wetland + Zn-EDTA) gave maximum Gross return ($87961.67 \text{ ` ha}^{-1}$ ), net return ( $48928.22 \text{ ` ha}^{-1}$) and also lesser B:C ratio (1.25) due to higher cost of Zn-EDTA as compare to M_2Z_1 (Wetland + $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) B : C ratio (1.27). Treatment combination of M_3Z_0 (Farmer practice+ Control) was recorded minimum gross return ($68417.50 \text{ ` ha}^{-1}$ ), net return ( $32963.78 \text{ ` ha}^{-1}$) and also B : C ratio (0.92) over other treatments.



SUMMARY AND CONCLUSION

The present investigation entitled “**Effect of crop establishment method and different source of Zinc on growth, yield and quality of rice (*Oryza sativa* L.) cv Pusa-44**” was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India during rainy (*Kharif*) season of 2013 with a view to test the comparative performance of different methods of crop establishment viz. farmer’s practice, wetland transplanting and SRI and four different source of Zinc. *i.e.* Zn₁ (ZnSO₄.7H₂O), Z₂ (Zn-EDTA) and Z₃ (ZnSO₄.H₂O) The objectives of the experiment were:

1. To study the effect of crop establishment method and different source of Zinc on growth, yield and quality of rice.
2. To find out the most appropriate crop establishment method and use of different Zinc source application on transplanted rice.
3. To workout economics of different treatments.

The experiment was laid out in a split plot design with three main plot treatments and four sub plot treatment consisting of 12 treatment combinations. Various observations were recorded during the course of investigation including growth characters; yields attributes and yield as affected by crop establishment method and different sources of Zinc. Growth parameters were recorded at various phenological stages starting from 30 DAT followed by 60, 90 DAT and at harvest which included plant height, number of tillers hill⁻¹, leaf area index and dry matter accumulation hill⁻¹. Similarly number of yield attributes like panicle length, panicle weight, test weight, No. of panicles per m², grain and straw yield and total uptake of the nutrients, were also noted to assess the effect of treatment. And similarly the quality parameters like protein content (%), carbohydrate (CH₂O)_n and protein yield (Kg/ha) were also noted to assess the effect of treatments.

The data collected during the course of experimentation were subjected to statistical analysis to draw valid conclusion. Finally the different treatments were assessed for their gross return, net return and benefit: cost ratio. The important finding and broad conclusion emerging from the investigation are summarized here under:

6.1 Effect of crop establishment method on yield and yield attributes of rice

Effect of crop establishment method brought about significant increase in growth component at different growth stages such as plant height, number of tillers hill⁻¹, leaf area index and dry matter production hill⁻¹.

Lucid effect of crop establishment method was also observed on yield and yield attributing characters viz. No. of panicles m⁻², panicle length, panicle weight and 1000 grain weight. The crop establishment method of SRI further improved yield attributing characters as well as grain and straw yields. Wetland transplanting and farmer's practice significantly at par to each other in respect to the yield attributes, grain and straw yields. The application of SRI produced significantly higher nitrogen, phosphorus and potassium uptake by rice grain. The uptake of nitrogen, phosphorus and potassium by grain were also higher under application of SRI. The protein content and protein yield by grain were significantly higher in SRI as compared to wetland transplanting and farmer's practices.

6.2 Effect of different sources of Zinc on yield and yield attributes of rice

Application of Zn-EDTA @ 1.0 (kg ha⁻¹) as ½ basal and as ½ foliar gave significantly increased the growth parameters such as plant height, Nos. tillers hill⁻¹, leaf area index and dry matter accumulation hill⁻¹ with other treatments .

The yield and yield attributing characters were also higher under application of Zn-EDTA @ 1 (kg ha⁻¹) followed by ZnSO₄.7H₂O @ 10.0 kg Zn ha⁻¹ and

ZnSO₄.H₂O @ 5.0 kg ha⁻¹ both (as ½ basal and as ½ foliar) as compared to Control (No use of any Zinc sources).

Yield attributes and yields of (grain and straw) rice were also influenced significantly by different sources of Zinc. Maximum number of panicles per m⁻², panicle length, panicle weight, number of grains per panicle, grain filling per cent, test weight, grain yield, straw yield, and harvest index, were recorded under M₁Z₂ (SRI + Zn-EDTA) application of Zn-EDTA @ 1.0 kg Zn (ha⁻¹) with other treatment. The minimum yield attributes was recorded under M₃Z₀ (Farmer practice's + Control) as compared to other treatment.

Data on quality parameters clearly showed that Zn-EDTA @ 1.0 (kg ha⁻¹) resulted in significant improvement in hulling, milling, head rice recovery (%), kernel length (mm), kernel breadth (mm), kernel length after cooking, elongation ratio, amylase content (%), alkali value, protein content, and protein yield with other treatment .

The application of different sources of Zinc was recorded there is no significant difference under nitrogen, phosphorus and potassium uptake by grain, straw and total uptake by the crop at harvest.

6.3 Economics of rice cultivation

Data pertaining to show that treatment combination of M₁Z₂ (SRI + Zn-EDTA) gave higher gross return (92608.03 ` ha<sup>-1</sup>), net return (56184.37 ` ha⁻¹) and also B : C ratio (1.54) followed by M₁Z₁ (SRI + ZnSO₄.7H₂O) and M₁Z₃ (SRI+Zn-SO₄.H₂O). Treatment combination of M₂Z₂ (Wetland + Zn-EDTA) gave maximum Gross return (87961.67 ` ha<sup>-1</sup>), net return (48928.22 ` ha⁻¹) and also lesser B:C ratio (1.25) due to higher cost of Zn-EDTA as compare to M₂Z₁(Wetland + ZnSO₄.7H₂O) B:C ratio(1.27). Treatment combination of M₃Z₀ (Farmer practice+ Control) was recorded minimum gross return (68417.50 ` ha<sup>-1</sup>), net return (32963.78 ` ha⁻¹) and also B:C ratio(0.92) with other treatment.

6.4 Conclusion

On the basis of one years of experiments the following conclusions have been drawn.

1. Rice variety Pusa-44 responded favourably to the crop establishment method i.e. SRI for achieving higher yield at Varanasi.
2. Individually zinc application $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ @ 10 kg ha^{-1} (half through soil as basal and rest half through foliar spray at 1% concentration on 30 DAT) be made for higher productivity and enriched rice quality of high nutritional value.
3. Individually application of Zn-EDTA @ 1 kg ha^{-1} (half through soil as basal and rest half through foliar spray at 0.5% concentration on 30DAT) be followed for higher productivity and greater nutritional value.
4. Application of $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ @ 5 kg ha^{-1} (2.5 kg through soil as basal and 2.5 kg through foliar spray at 0.5% concentration on 30 DAT) be made to get higher productivity and greater nutritional value.

Since the experiment was conducted for one year only thus, needs further investigation to confirm the results.



BIBLIOGRAPHY

- Agarwal, SK, Suraj, B and Bhan, S, Effect of levels of zinc sulphate application on the yield in rice-wheat cropping sequence. *Indian Journal of Agriculture Research*, **31** (3) 174-178, 1997.
- Ahmad, HR, Aziz, T, Hussain, S, Akraam, M, Sabir, M, Kashif, SR and Hanafi, MM, Zinc enriched farm yard manure improves grain yield and grain Zn concentration in rice grown on a saline-sodic soil. *International Journal of Agriculture and Biology*, **14**, 787-792, 1992.
- Alamdari, MG, Rajurkar, NS, Patwardhan, AM and Mabasser, HR, The effect of sulphur and sulphate fertilizers on Zn and Cu uptake by the rice plant (*Oryza sativa* L.), *Asian Journal of Plant Science*, **60** (2), 407-410, 2007.
- Ali, M, Ladha, JK, Rickman, J and Lales, JS, Nitrogen dynamics in lowland rice as affected by crop establishment and nitrogen management. *Journal of Crop Improvement*. **20**, 1/2, pp.89-105, 2007.
- Alloway, BJ, Zinc in soils and crop nutrition, Paris, France: IFA; and Brussels, Belgium: IZA, 2008.
- Alloway, BJ, Zinc in Soils and Crop Nutrition. *International Zinc Association, Brussels, Belgium*, 2004.
- Andrianaivo, B, Evaluations of the System of Rice Intensification in Fianarantsoa Province of Madagascar. In : Assessments of the System of Rice Intensification (SRI) : Proceedings of the International Conference, Sanya, China, April 1-4, 2002, ed. by N. Uphoff *et.al.*, pp 140-142, 2002.
- Anonymous, Agriculture Situation in India, 2012.
- Arnon, DI and Stout, PR, Agronomy Terminology. Published by Hony Secretary, Indian Society of Agronomy, Div. of Agronomy, IARI, New Delhi. pp. 307-312, 1939.
- Asewar, BV, Dahiphale, VV, Chavan, GV, Katare, NB, Sontakke, JS, Effect of ferrous sulphate on grain yield of upland Basmati rice. *Journal of Maharashtra Agricultural Universities*, **25** (2): 209-210, 2000.
- Barison, J, Nutrient use efficiency and nutrient uptake in conventional and intensive (SRI) rice cultivation system in Madagasker. *ciifad@cornel.edul*, 2002.
- Behera, SK, Singh, D and Dwivedi, BS, Change in fractions of iron, manganese, copper and zinc in soil under continuous cropping for more than three decades. *Commun. Soil Science Plant Anal.* **40**, 1-28, 2009a.

- Behera, SK, Singh, MV and Lakaria, BL, Micronutrient deficiencies in Indian soil and their amelioration through fertilization. *Indian Farming*, **59** (2), 28-31, 2009b.
- Biswas, DR, and Dravid, MS, P and Zn interaction as influenced by Mg on yield and nutrient uptake by rice under varying moisture regimes. *Annals of Agricultural Research New Series*, **22**(3): 329-334, 2001.
- Broadley MR, White, PJ, Hammond JP, *et al.* Zinc in plants. *Newphitol*, **173**, 677-702, 2007.
- Cakmak I, Enrichment of cereal grains with zinc: agronomic or genetic biofortification? *Plant Soil*. **302**, 1–17, 2008.
- Cakmak, I, Enrichment of fertilizers with zinc – An excellent investment for humanity and crop production in India. *J. Trace Elem. Med. Bio.* **23**, 981-989, 2009.
- Cakmak, I, Kalayci, M, Ekiz, H, Braun, HJ and Yilmaz, A, Zinc deficiency as an actual problem in plant and human nutrition in Turkey: a NATO Science for Stability Project. *Field Crops Research*, **60**,175–188, 1999.
- Cakmak, I, Possible role of zinc in protecting plant cells from damage by reactive oxygen species. *New Phytology*, **146**, 185-205, 2000.
- Cakmak, I, Torun A, Millet E, Feldman M, Fahima T, Korol A and Nevo E, Braun HJ, Ozkan H, Triticum dicoccoides: an important genetic resource for increasing Zn and Fe concentration in modern cultivated wheat. *Soil Science Plant Nutrition*, **50**: 1047-1054, 2004.
- Chandrapala, AG, Yakadri, M, Kumar, RM and Raj, GB, Establishment, Zn and S application in rice, *Indian Journal of Agronomy*, **55** (3): 171-176, 2010
- Chhibba, IM, Nayyar, VK and Takkar, PN, Direct and residual effect of some Zn carriers in rice- wheat rotation. *J. Indian Soc. Soil Science*, **37**, (3): 585-587, 1989.
- Curl, EA, and Truelove, B, “ The Rhizosphere” Springer- Verlag, New York, 1986.
- Dargan, KS, Singh, OP and Gupta, IC, Crop production in salt affected soils. Oxford and IBH publishing Co. Pvt. Ltd., New Delhi, pp. 28-29, 1982.
- Datta, SK, and Khush, GS, Improving rice to meet food and nutritional needs – Biotechnological approaches. *Journal of Crop Production*. **6**, (1&2): 224- 229, 2002.

- Deb, DL, Strategy for increasing micronutrient use to improve agricultural production. *Fert. News* **34**, (12): 73-77, 1989.
- Devarajan, R and Krishnasamy, R, Effect of Zn- enriched manures on rice yield. *Madras Agriculture Journal*, **83**, (5): 280-283, 1996.
- Dixit, AK, Sharma, BC, Bali, AS and Bazaya, BR, Refinement of basmati rice establishment techniques for higher productivity and profitability and its impact on succeeding conventionally and zero tilled sown wheat crop. In: *SRI India 2007. Second National Symposium on System of Rice Intensification (SRI) in India-Progress and Prospects held at Agartala, Tripura, India during 3-5 October, 2007.*
- Dravid, MS and Goswami, NN, Effect of farm yard manure P and Zn on dry matter yield and uptake of P, K, Zn and Fe by rice under non-saline and saline conditions. *Journal Nuclear Agriculture Biology*, **16**, 201-205, 1987.
- Fageria, NK, Bajigar, VC and Clark, RB, Micronutrients in crop production. *Advances in Agronomy*. **77**, 187-266, 2002.
- Gangwar, FS, Singh, KK and Sharma, SK, Effect of tillage on growth, yield and nutrient uptake in wheat after rice in indogangetic plain of india. *Journal of Agriculture Science*, **142** (4): pp.453-459, 2004.
- Gao, X, Zou, C, Fan, X, Zhang, F and Hoffland, E, Form flooded to aerobic conditions in rice cultivation: Consequences from Zn uptake, *Plant and Soil*, **280**, 41-47, 2006.
- Ghatak, R, Jana, PK, Sounda, G, Ghosh, RK and Bandopadhyay, P, Responses of transplanted rice to Zn fertilization at farmer field on red and laterite soil of West Bengal. *Journal Interacademia*, **9** (2): 231-234, 2005.
- Giordano, PM, Noggle, JC and Mortvedt, JJ, Zinc uptake by rice as affected by metabolic inhibitions and competing cations. *Plant and Soil*, **41**, 637-646, 1974.
- Govindaswami, S and Murthy, PSN, Effect of manorial and cultural practices on the quality characterises. Tech. Rep, CRRI, Cuttack, Orissa. 1966.
- Govindaswami, S, Increasing rice production by better breeding and technology, Proceedings of the symposium on “Science and India’s Food Problem” sponsored by the National Institute of Science, India. 336-346, 1967.
- Graham RD, Senadhira, D, Beebe, S, Iglesias, C, Monasterio, I, Breeding for micronutrient density in edible portions of staple food crops: Conventional approaches. *Field Crops Research*, **60**: 57–80, 1999.

- Graham, RD and Welch, RM, Breeding for staple food crops with high micronutrient density. In Worker papers on agricultural strategies for micronutrients, ed. HD, Bouis, 1–72. Washington, DC: International Food Policy Research Institute. 1996.
- Grewal, HS, Lu, Z and Graham, RD, Influence of subsoil zinc on dry matter production, seed yield and distribution of zinc in oilseed rape genotype differing in zinc efficiency. *Plant and Soil*, **192**, 81-189, 1997.
- Gupta, A and O'Toole, Zinc fertilization on flooded rice in vertisols of Hyderabad. *Journal Nuclear Agriculture Biology*, **12**, (4)96-99, 1986.
- Gurmani, AH, Yousaf, M and Khattak, JK, Effect of zinc, copper, iron and manganese on yield of rice. National Seminar on micronutrient in soils and crops in Pakistan (Peshawar), Dec. 13-15, 1998, pp. 170-178, 1988
- IFA, Help eliminate the fifth leading disease risk factors in developing countries. In: Fertilizer and agriculture. January 2007, K. E. (ed.), International Fertilizer Agency, Paris, France. 6 p, 2007.
- Indulkar, BS and Malewar, GU, Response of rice to different zinc sources and their residual effect on succeeding chickpea. *Indian Journal of Agronomy*, **36**, 5-6, 1991.
- International fertilizer association (IFA) 2004 how can the fertilizer industry contribute to the nutrition security challenge. IFA International symposium on micronutrients, New Delhi, India, 23-24 February 2004.
- Ishimaru, Yasuhir, Khurram, Bashir, and Naoko K. Nishizawa. Zn Uptake and Translocation in Rice Plants. *Rice*. **4**: 21–27, 2011.
- Jagtap, DN, Mahadkar, UV and Chavan, LS, Productivity and economics of rice influenced by different crop establishment methods and fertilizer sources. *Agricultural Journal*; **7**, 1, pp32- 3, 2012.
- Jana, PK, Ghatak, R, Sounda, G, Ghosh, RK and Bandhyopadhyay, P, Effect of zinc fertilization on yield N,P,K and Zn uptake transplanted rice at farmers field of red and lateritic soils of West Bengal, *Indian Agriculturist*, **53** (3/4), 129-132, 2009.
- Jat, SL, Shivay, YS and Parihar CM, Dual purpose summer legumes and zinc fertilization for improving productivity and zinc utilization in aromatic hybrid rice (*Oryza sativa*). *Indian Journal of Agronomy*, **56** (4): 328- 333, 2011.
- Jayadeva, HM and Setty, TKP, Influence of nitrogen and crop establishment techniques on crop productivity and nutrient budget in rice. *Madras Agricultural Journal*, **97**: 7/9, pp.223-229, 2010.

- Kanda, C and Dixit, L. Effect of zinc and nitrogen fertilization on summer rice. *Indian Journal of Agronomy*, **40** (2): 695-697, 1995.
- Karak, T, Das, DK and Maiti, D, Yield and Zn uptake in rice (*Oryza sativa* L.) as influenced by sources and times of Zn application, *Indian Journal of Agricultural Sciences*, **76** (6): 346-8, 2006.
- Karak, T, Singh, UK, Das, DK, and Yakov, Kuzyakov, Comparative efficacy of Znso₄ and Zn-EDTA application for fertilization of rice (*Oryza sativa* L.), *Archives of Agronomy and Soil Science*, **51**, (3), 253-264, 2005.
- Katyail, JC, Rattan, RK and Datta, SP, Management of Zn and Bo for sustainable food production, *Fertilizer News*, **94** (12), 83-89, 2004.
- Khan, MU, Qasim, M and Jamil, M, Effect of different levels of Zn on the yield and yield components of rice in different soils of D. I. Khan, Pakistan. *Sarhad Journal of Agriculture*, **21**, (1): 63-69. 2005
- Krishnaswamy, R, Shannugam, M, Poongothai, S, Valiappahn, K, Mani, S, Vanagamudi, M, Savithri, P and Devrajan, R, Twenty five years of micronutrient research in soils and crops of Tamil Nadu, Dept. Of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University Coimbatore, India, 1994.
- Kulandaivel, S, Mishra, BN, Gangiah, B and Mishra, PK, Effect on levels of zinc and iron and their chelation on yield and soil micronutrient status in hybrid rice (*Oryza sativa*) - wheat (*Triticum aestivum*), cropping system. *Indian Journal of Agronomy*, **49**, (2): 80-83, 2004.
- Kumar, B and Singh, SP, Zinc management in nursery and transplanted rice (*Oryza sativa*, L.), *Indian Journal of Agronomy*, **41**, (1), 153-154, 1996.
- Kumar, D, Chauhan, RPS, Singh, BB and Singh, V, Response of rice (*Oryza sativa*) to zinc sulphate incubated and blended with organic materials in sodic soil. *Indian Journal of Agricultural Sciences*, **69**, (6): 402-405, 1999
- Kumar, T and Kumar, V, Effect of rates and methods of zinc application on yields economics and uptake of zinc by rice crop in flood prone situation, *Asian Journal of Agronomy of Soil Science*, **4** (1), 96-98, 2010.
- Latif, MA, Ali, MY, Islam, MR and Rashid, MH, Compilation Report on Extension of the System of rice Intensification (SRI) through verification. [http:// ciifad. Cornel edu/ sri/ wrrc/ bd wrre](http://ciifad.Cornel.edu/sri/wrrc/bdwrre), 2004.
- Laulanie, H, The system de riziculture intensive malagache, *Tropicultura* (Brussels), **11**, 110-114, 1993

- Li Zhi Gang, Ye Zheng Qian, Fang Yun Ying and Yang Xia, Effect of zinc on plant growth and zinc partitioning in rice plant. *Chinese Journal of Rice Science*, **17**, (1) 61-66, 2003
- Mali, CV and Shaikh, AR, Management of zinc sources in rice-gram cropping system. *Journal of Maharashtra Agriculture University*, **19**, 4-7, 1994.
- Mandal, L, Maiti, D and Bandyopadhyay, P, Response of zinc in transplanted rice under integrated nutrient management in new alluvial zone of west Bengal. *Oryza*, **46**, (2): 2009.
- Mani, AK, Duraisamy, P, Thilagavathi, T and Parasuramam, Effect of zinc enrichment on organic waste on dry matter production, yield economics in rice (*Oryza sativa*), in entisol of north-western Tamil Nadu. *Indian Journal of Agronomy*, **46**, (1) 89-9, 2001.
- Mankotia, BS, Shekhar, J and Negi, SC, Performance of rice in SRI (system of rice intensification), ICM (integrated crop management) and conventional transplanting methods with common date of transplanting in the mid hills of HP. *Haryana Journal of Agronomy*, **22**: 1, pp.68-70, 2006.
- Marschner, H, "Mineral Nutrition of Higher Plants". Academic Press, San Diego, 1995.
- Martens, DC and Westernmann, DT, Fertilizer application for correcting micronutrient deficiency in "Micro nutrients in Agriculture", 2nd Edition (JJ Mortvedt, FR Cox, LM Shuman and RM Welch, Eds.), pp. 549-592, 1991.
- Masuda, H, Suzuki, Morikawa, KC, Kobayashi, T, Nakanishi, H, Takahashi, M, Saigusa, M, Mori, S and Nishizawa, NK, Increase in Iron and Zinc Concentrations in Rice Grains Via the Introduction of Barley Genes Involved in Phytosiderophore Synthesis. *Rice*, **1**:100–108, 2008.
- Mollah, MZI, Talukdar, NM, Islam, MN, Rahman, MA and Ferdous, Z, Effects of nutrients content in rice as influenced by Zn fertilization, *World Applied Sciences Journal*, **6**, (8), 1082-1088, 2009.
- Nagarathna, TK, Shankar, AG and Udayakumar, M, Assessment of genetic variation in zinc acquisition and transport to seed in diversified germplasm lines of rice (*Oryza sativa* L.). *Journal of Agriculture Technology*, **6**:171–178, 2010.
- Naik, SK and Das, DK, Relative performance of chelated zinc and zinc sulphate for lowland rice (*Oryza sativa* L.). *Nutrient Cycling in Agro-ecosystems*, **81**(3): 219-227, 2008.

- Nambiar, KKM and Motiramani, DP, Zinc nutrition on the yield and nutrient composition of chickpea as related to four soil types. *Journal of Crop Science*, 152: 165- 172, 1983.
- National Research Council Recommended Dietary Allowances sub- committee on the Tenth Edition of the RDAs Food and Nutrition Board, Commission on Life Sciences 10th ed. National Academy Press, Washington, DC, 1989.
- Nene, YL, Symptoms, causes and control of *Khaira* disease of paddy. *Bull. Indian Phytopathology Society*, **3**, 97-101, 1966
- Neue HU, Quijano, C, Senadhira, D, Setter, T, Strategies for dealing with micronutrient disorders and salinity in lowland rice systems. *Field Crops Research*, **56**, 139–55, 1998.
- Norman, RJ, Wilson, CE, Jr, and Slaton, NA, Soil fertilization and mineral nutrition in US mechanized rice culture. In “Rice: Origin, history and Production” (C W, Smith and RH, Dilday, Eds.), pp.31-412. *John Wiley, NJ, USA*, 2003.
- Panda, S, Cand Nayak RC, Effect of zinc on growth and yield of rice, *Indian Journal of Agronomy*, 19, 9-13, 1974.
- Pandey, N, Verma, AK, Anurag and Tripathi, RS., Integrated Nutrient Management in transplanted hybrid rice (*Oryza sativa* L.), *Indian Journal of Agronomy*, **52**, (1), 40-42, 200
- Parihar, SS, Effect of crop establishment method, tillage, irrigation and nitrogen on production potential on rice-wheat cropping system, *Indian Journal of Agronomy*, **49**, (1): pp.1-5, 2004.
- Patil, KD and Meisheri, MB, Direct, residual effect of applied zinc along with FYM on rice in soil of Konkan region of Maharashtra. *Annals of Agricultural Research*. **24**, (4): 927-933, 2003.
- Pearson, JN, and Z, Rengel. Distribution and remobilization of Zn and Mn during grain development in wheat. *Journal of Experimental Botany*, **45**:1829–1835, 1994.
- Pfeiffer, WH, Mc Clafferty B, Biofortification: Breeding Micronutrient- Dense Crops. In Kang MS (Ed) Breeding major food staples. Blackwell Science Ltd (In press), 2004.
- Pooniya, V and Shivay , YS, Enrichment of basmati rice grain and straw with Zinc and Nitrogen through fertilization and summer green manuring under indoganetic plains of India, *Journal of Plant Nutrition*, **36**(1): 91-117, 2013.

- Prasad, AS, Zinc in human health: effect of zinc on immune cells. *Mol Med*, **14**, (5-6): 353-357, 2008.
- Prasad, B and Umar, SM, Direct and residual effect of soil application of zinc sulphate on yield and zinc uptake in a rice -wheat rotation *J. Indian Soc. Soil Sci.* **41**, (1): 192-194, 1993.
- Prasad, B, Sharma, MM, and Sinha, SK, Evaluating zinc fertilizer requirement on Typic Haplaquent in the rice-wheat cropping system. *Journal of Sustainable Agriculture*, **19**, (3), 39-49, 2002.
- Prasad, R, Shivay, YS and Kumar, D, Zinc fertilization of cereals for increased production and allevation of zinc malnutrition in India. *Agricultural Research*, 2013
- Prasad, Rajendra, Zinc in soils and in plant, human & animal nutrition. (Special Issue:Seminar Special). *Indian Journal of Fertilizers*, 2: 9, 103-119, 2006.
- Prashad, B, Prashad, J and Prashad, R, Nutrient management for sustainable rice and wheat production in calcareous soil amended with green manuring, organic manures and zinc. *Fertilizer News*, **40**, 39-45, 1995
- Qui, LC Pan, J and Daun, BW, The mineral nutrient component and characteristics of coloured and white brown rice. *Chinese Journal of Rice Science*, **7**, (2): 95-100, 1993
- Rahman, MA, Jahiruddin, M, and Islam, MR, Critical limit of Zinc for rice in calcareous soils, *Journal of Agriculture & Rural Development* (Gazipur), **11**, (1/2), 43-47, 2007.
- Rao, CP, Nutrient utilization efficiency of rice influenced by different sources and levels of phosphorus and rates of zinc., *Annals of Agricultural Research*, **24**, (1), 7-11, 2003.
- Rathore ,GS, Khanparia, RS, Gupta, GP, Dubey, SB. Sharma, B Land Tomar, VS, Twenty five years of micronutrient research in soils and crops of Madhya Pradesh, Dept. Of Soil Science. Agricultural Chemistry, J.N.K..Vishwa-Vidyalaya, Jabalpur, 1995.
- Refuerzo, L, Mercado, EF, Arceta, M, Sajese, AG, Gregorio G., Singh, R, K, QTL mapping for zinc deficiency tolerance in rice (*Oryzasativa* L.). *Philipp Journal of Crop Science*, 34:86, 2009.
- Regel, Z and Graham, RD, Importance of seed Zn content for rice growth on Zn-deficient soil. *Plant and Soil*, **173**, 259-266, 1995.

- Rengel, Z and Graham, RD, Importance of seed zinc content for wheat growth on zinc deficient soil. II. Grain yield. *Plant and Soil*, **173**, 267-274, 1995.
- Ruel, MT and Bouis, HE, Plant breeding: a long-term strategy for the control of Zn deficiency in vulnerable populations. *American Journal of Clin Nutr Suppl.* **68**, 488- 494, 1998.
- Sachdev, P and Deb, DL, Influence of gypsum and farmyard manure on fertilizer zinc uptake by wheat and its residual effect on succeeding rice and wheat crops in a sodic soil. *Journal of Nuclear Agriculture Biology*, **19**, (3): 173-178. 1990.
- Saha, A and Bharti, V, Effect of different crop establishment methods on growth, yield and economics of rice (*Oryza sativa* L.). *Environment and Ecology*, 2010.
- Sahu, S, K, Mishra, GN and SC, Effect of Zn sources of uptake of Zn and other micro nutrient by rice on vertisols. *Journal of Indian Society of Soil Science.* **42** (3): 487-489, 1994
- Sandstead, H, Zinc deficiency: a public health problem? *American Journal of Dis Child.* **145**:853–9, 1991.
- Saraswat, VK and Bansal, KN, Methods of zinc application and its effect on yield and zinc content of rice (*oryzasativa*) and wheat (*Triticum vulgare*) *Madras Agriculture Journal*, **78** (5-8): 174-177, 1991
- Shanmugam, PM and Veeraputhran, R, Effect of organic manure, biofertilizers, inorganic nitrogen and zinc on growth and yield of rabi rice (*Oryza sativa* L.). *Madras Agricultural Journal*, **87**, (1/3): 90-93, 2001.
- Sharma, CP, Sharma, PN, Bisht, SS and Nautiyal, BD, Zinc deficiency induced changes in cabbages in cabbage p.601-606, In Proc. 9th Plant Nutr. Colloq. (A scaife ed.), W awick, England 22-27 Aug., commonwealth Agric. Bur. (CAB), Farnham house, Sough, U.K., 1982.
- Sharma, RP, Raman, KR, Pathak, SK, Jha, RN and Chattopadhyaya, Effect of crop establishment methods and tillage and practices on crop productivity, profitability and soil health of rice wheat cropping system..*Farming Systems Research and Development*, **12**, (1&2): pp.42-46, 2006.
- Shivay, YS, Kumar, D and Prasad, R, Effect of Zn enriched urea on productivity, zinc uptake and efficiency of an aromatic rice-wheat cropping systems. *Nutr Cycl Agroecocyst*, **81**, 229-243, 2008.
- Shivay, YS, Prasad, R and Rahal, A, Genotypic variation for productivity, Zn utilization efficiencies and kernel quality in aromatic rice under low available Zinc conditions. *Journal of Plant Nutrition*, **33**, (12), 1835-1848, 2010.

- Silanpaa, M, Micronutrient Assessment at the country level- An international study Food and Agriculture Organization (FAO) of the United Nations, Rome
- Singh, A and Shivay, Y, S, Residual effect of summer green manure crops and Zn fertilization and quality and Zn concentration of durum wheat (*Triticum durum* Desf.) under a basmati rice-durum wheat cropping system, Biological agriculture and Horticulture. International Journal for Sustainable, Production Systems, **29**, (4), 271-287, 2013.
- Singh, AP, Raha, P, and Yadav, PK, Effect of sulphur and manganese fertilization on Zn content and quality of rice bran oil. *Indian Journal of Agricultural Biochemistry*, 18: 1, 19-23, 2005.
- Singh, B, Senthil Kumar, AM, Singh, BK and Usha, K, Improving zinc efficiency of cereals under zinc deficiency, *Current Science*. 88, 36-44, 2005.
- Singh, B, Senthil Kumar, AM, Singh, BK and Usha, K, Improving zinc efficiency of cereals under zinc deficiency, *Current Science*, **88**, 36-44, 2005.
- Singh, K, Deo, C, Bohra, JS, Singh, JP and Singh, RN, Effect of iron carriers and compost application on rice yield and their residual effect on succeeding wheat crop in Entisol. *Annals of Agricultural Research*, **13**, (2), 181-183, 1992.
- Singh, K, K, Jat, AS and Sharma, SK, Improving productivity and profitability of rice-wheat cropping system through tilage and planting management. *Indian Journal of Agriculture Science*, **75**, (7), pp.396-399, 2005.
- Singh, K, Raj, L and Ghose, RL, Zinc translocation to wheat roots and its implications for a phosphorus/zinc interaction in wheat plants. *Journal of Plant Nutrition*, **13**, 1499-1512, 1996.
- Singh, RM and Jain, GL, Response of paddy to Fe and Zn, *Indian Journal of Agronomy*, **9**, 273-276, 1964.
- Singh, TN, Singh, HP and Singh, G, Zinc requirement for rice wheat sequence. *International Rice Research Newsletter*, **12**, (4): 64-65, 1987.
- Slaton, NA, Gbur, Jr., EE., Wilson, Jr, C, E and Norman, RJ, Rice response to granular zinc sources varying in water-soluble zinc. *Soil Science of America Journal* **69**, 443-452, 2005.
- Sommer, AL and Lipman, CB, Agronomy terminology. Published by Hony. Secretary, Indian society of Agronomy, *Division of Agronomy, IARI, New Delhi*. 307-312, 1926.

- Sridevi, G, Rajkannan B and Surendran, U, Effect of Zn enriched FYM and cowdung on yield of rice (ADT-45), *Crop. Research*, **40**, (1,2,3), 25-28, 2010.
- Sridevi, V, Jeyaraman, S, Ramasamy, S, Chinnusamy, C, Muthukrishnan, P, Subalakshmi Lokanadhan and Thavaprakash, N, Yield and economics of transplanted rice as influenced by crop establishment methods, weed and nutrient management practices. *Madras Agricultural Journal*, **99**: 4/6, pp.325-328, 2012.
- Subbaiah, VV, Sreemannarayana, B, Sairam, A, Kumar, PRP, Prasadini, PP, Effect of zinc levels and its relative proportion to iron and manganese content in 3rd leaf on Zn deficiency and grain yield of lowland rice. *Journal of Research APAU*, **22**, (3/4): 135-136, 1994.
- Suri, IK, Devkumar, C, Zincated urea, A new zinc micronutrient fertilizer (Indian), *Journal of Fertilizers*, **2**, (7), 19-22, 2006.
- Suzuki, M, Morikawa, KC, Nakanishi, H, Takahashi, M, Saigusa, M, Mori, S, *et al.* Transgenic rice lines that include barley genes have increased tolerance to low iron availability in a calcareous paddy soil. *Soil Science Plant Nutrition*, **54**, 77– 85, 2008a.
- Swarup, A. Iron, zinc and manganese nutrition of wetland rice (*Oryza sativa* L.) on a gypsum amended sodic soil. *Plant and Soil*, 155/156: 477-480, 1993.
- Takkar, PN and Singh, T, Zinc nutrition of rice as influenced by rates of gypsum and Zn fertilization of alkali soils. *Agronomy Journal*, 70: 447-450, 1978.
- Tripathi, AK and Tripathi, HN, Studies on zinc requirement of rice (*Oryza sativa*) in relation to different modes of zinc application in nursery and rates of ZnSO₄ in field *Haryana Journal of Agronomy*, **20**, (1/2), 77-79, 2004.
- Tripathi, SC, Nagrajan, S and Chauhan, DS, Evaluation of zero tillage in wheat under different methods of rice transplanting. *Indian Journal of Agronomy*, **44**, (1): pp. 219-222, June 1999.
- Tripathi, SD, Micronutrient status of rice growing belt of Varanasi division with special reference to zinc and iron. Ph. D. thesis, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India, 1993.
- Ugurluoglu, H and Kacar, B, Effect of different Zn sources on the growth of rice (*Oryza sativa*, L.) *Turkistan Journal of Agricultural Forestry*, **20**: 473-8, 1996.
- Uphoff, N, Possible explanations for the productivity gains achieved with the System of Rice Intensification (SRI). (In): Transitions in Agriculture for enhancing

- Water Productivity. Proceedings of an International Symposium held in Killikulam, Tamil Nadu, India during 23-25, September 2003, 2005.
- Varshney, Poonam, Singh, SK and Srivastava, PC, Frequency and rates of Zinc application under hybrid rice- wheat sequence in a mollisol of Uttrakhand, *Journal of the Indian Society of Soil Science*, 56, 1, 92-96, 2008.
- Verma, TS and Neue, HU, Effect of soil salinity level and zinc application on growth, yield and nutrient composition of rice. *Plant and Soil*, **82**: 3-14, 1984.
- Welch, RM and Graham, RD, A new paradigm for world agriculture: meeting human needs: productive, sustainable, nutritious. *Field Crops Research*, **60**, 1-10, 1999.
- Wissuwa, M, Ismail, AM, Graham, RD, Rice grain zinc concentrations as affected by genotype, native soil-zinc availability, and zinc fertilization. *Plant Soi*, **306**, 37-48, 2008.
- Wissuwa, M, Ismail, AM, Yanagihara, S, Effects of zinc deficiency on rice growth and genetic factors contributing to tolerance. *Plant Physiology*, **142**, 731-41, 2006.
- Yao Zheng, Zhao Jinglin, Tai Halchen, Yao Z Zhao, JY and Tai, HC, Effect of two termented organic fertilizers on some soil, trace elements. *Acta – Agriculturaw- Shanghal*, **9**, (4): 53-58, 1998.
- Yilmez, AH, Ekiz, B, Torun, I, Guttekin, S, Karanlik, SA, Bagci and I, Cakmak, Effect of different zinc application methods on grain yield and zinc concentration in wheat cultivars grown on zinc deficient calcareous soils. *Journal of Plant Nutrition*, **20**, 461-471, 1997.
- Yoshida, S, Ahu, JS and Forna, DA, Occurrence, diagnosis and correction of zinc deficiency of lowland rice. *Soil Sci. Plant Nutrition*, **19**, 83-94, 1973.
- Yoshida, S, Climate and rice, IRRI, Philippines.p -211. 1972.
- Zhang, FS and Barrow, NJ, Mobilization of iron and manganese by plant- borne and synthetic metal chelators. Plant nutrition from genetic engineering to field practice. Proceeding, held on Sept. 21-26, 1993, *Perth*, **115-118**.1993.



APPENDICES

Appendix I. Cost of cultivation of rice (SRI transplanting)

S.No.	Operation Material	Input	Rate (₹)	Cost (₹)
1.	Nursery (500 Sq.m.)			
	(a) Nursery preparation			
	(i) One discing	One tractor (35 HP) for 0.1 hours	400/hr.	40.00
	(ii) Puddling and Planking	One tractor (35 HP) for 0.3 hours	400/hr.	120.00
	(b) Layout	1 man day	160/ man day	160.00
	(c) Sowing	2 man days	160/ man day	320.00
	(d) Seed	5 kg	40/ kg	200
	(e) Fertilizer and manure	7 kg Urea	6.20/ kg	43.10
		5 kg DAP	24.80/ kg	124.00
		3 kg MOP	17.68/ kg	53.04
		62.5 FYM	0.80/Kg	50.00
	(f) Labour charge	1 man day	160/ man day	160.00
2.	Field preparation			
	(a) one discing	One tractor (35 HP) for 4 hours	400/hr.	1600.00
	(Puddling)	One tractor (35 HP) for 4 hours	400/hr.	1600.00
3.	Layout	6 man days	160/ man day	960.00
4.	Uprooting of seedling	4 man days	160/ man day	640.00
	Transplanting	30 man days	160/ man day	4800.00
6.	Fertilizer application	262.28 kg Urea	6.20/kg	1626.136
		163.04 kg DAP	24.80/kg	4043.392
		100 kg MOP	17.68/kg	1768.00
6.	Weed management			
	(a) Manual weeding	10 man days	160/ man day	1600.00
7.	Irrigation			
	(a) Water charges	2 Irrigation	300/ irrigation	600.00
	(b) Labour charges	6 man days	160/ man day	960.00
8.	Plant protection	-		
	Monocrotophos	700 ml (0.7L.)	76/100 ml	530.00
	Labour	6 man days	160/ man day	960.00
9.	Harvesting	20 man days	160/ man day	3200.00
10.	Threshing and Winnowing			
	(a)Threshing by tractor	One tractor (35 HP) for 4 hours	250/hr.	1000.00
	(b) Labour charge	6 man days	160/ man day	960.00
11.	Rental value of land	6 months	3000 per annum	1500.00
12.	Interest on working capital	6 months	14% per annum	1306.06
13.	Land revenue	6 months	120 per annum	60.00
Total				30983.668

Appendix II. Cost of cultivation of rice (Wetland transplanting)

S.No.	Operation Material	Input	Rate (₹)	Cost (₹)
1.	Nursery (500 Sq.m.)			
	(a) Nursery preparation			
	(i) One discing	One tractor (35 HP) for 0.1 hours	400/hr.	40.00
	(ii) Puddling and Planking	One tractor (35 HP) for 0.3 hours	400/hr.	120.00
	(b) Layout	1 man day	160/ man day	160.00
	(c) Sowing	2 man days	160/ man day	320.00
	(d) Seed	25 kg	40/ kg	1000.00
	(e) Fertilizer and manure	7 kg Urea	6.20/ kg	43.10
		5 kg DAP	24.80/ kg	124.00
		3 kg MOP	17.68/ kg	53.04
		62.5 kg FYM	0.80/Kg	50.00
	(f) Labour charge	1 man day	160/ man day	160.00
2.	Field preparation			
	(a) one discing	One tractor (35 HP) for 4 hours	400/hr.	1600.00
	(Puddling)	One tractor (35 HP) for 4 hours	400/hr.	1600.00
3.	Layout	6 man days	160/ man day	960.00
4.	Uprooting of seedling	15 man days	160/ man day	2400.00
5.	Transplanting	25 man days	160/ man day	4000.00
6.	Fertilizer manure application	262.28 kg Urea	6.20/kg	1626.136
		163.04 kg DAP	24.80/kg	4043.392
		100 kg MOP	17.68/kg	1768.00
6.	Weed management			
	(a) Manual weeding	20 man days	160/ man day	3200.00
7.	Irrigation			
	(a) Water charges	2 Irrigation	300/ irrigation	600.00
	(b) Labour charges	6 man days	160/ man day	960.00
8.	Plant protection	Nil	-	
9.	Harvesting	25 man days	160/ man day	4000.00
10.	Threshing and Winnowing			
	(a) Threshing by tractor	One tractor (35 HP) for 4 hours	250/hr.	1000.00
	(b) Labour charge	6 man days	160/ man day	960.00
11.	Rental value of land	6 months	3000 per annum	1500.00
12.	Interest on working capital	6 months	14% per annum	1306.06
13.	Land revenue	6 months	120 per annum	60.00
Total				33593.668

Appendix III. Cost of cultivation of rice (Farmer's practice)

S.No.	Operation Material	Input	Rate (₹)	Cost (₹)
1.	Nursery (500 Sq.m.)			
	(a) Nursery preparation			
	(i) One discing	One tractor (35 HP) for 0.1 hours	400/hr.	40.00
	(ii) Puddling and Planking	One tractor (35 HP) for 0.3 hours	400/hr.	120.00
	(b) Layout	1 man day	160/ man day	160.00
	(c) Sowing	2 man days	160/ man day	320.00
	(d) Seed	30 kg	40/ kg	1200.00
	(e) Fertilizer and manure	7 kg Urea	6.20/ kg	43.10
		5 kg DAP	24.80/ kg	124.00
		3 kg MOP	17.68/ kg	53.04
		62.5 FYM	0.80/Kg	50.00
	(f) Labour charge	1 man day	160/ man day	160.00
2.	Field preparation			
	(a) one discing	One tractor (35 HP) for 4 hours	400/hr.	1600.00
	(Puddling)	One tractor (35 HP) for 4 hours	400/hr.	1600.00
3.	Layout	6 man days	160/ man day	960.00
4.	Uprooting of seedling	20 man days	160/ man day	3200.00
5.	Transplanting	30 man days	160/ man day	4800.00
6.	Fertilizer manure application	262.28 kg Urea	6.20/kg	1626.136
		163.04 kg DAP	24.80/kg	4043.392
		100 kg MOP	17.68/kg	1768.00
6.	Weed management			
	(a) Manual weeding	20 man days	160/ man day	3200.00
7.	Irrigation			
	(a) Water charges	2 Irrigation	300/ irrigation	600.00
	(b) Labour charges	6 man days	160/ man day	960.00
8.	Plant protection	Nil	-	
9.	Harvesting	25 man days	160/ man day	4000.00
10.	Threshing and Winnowing			
	(a) Threshing by tractor	One tractor (35 HP) for 4 hours	250/hr.	1000.00
	(b) Labour charge	6 man days	160/ man day	960.00
11.	Rental value of land	6 months	3000 per annum	1500.00
12.	Interest on working capital	6 months	14% per annum	1306.06
13.	Land revenue	6 months	120 per annum	60.00
			Total	35453.728

Appendix IV. Cost of cultivation of different treatments (Rs. ha⁻¹)

Treatment	Symbols	Dose (kg ha ⁻¹)	Total amount of Zn-fertilizers	Rate ([^] kg ⁻¹)	Total cost of nutrients
Zn	Z ₀	0.0	00.0	00.00	0.00
	Z ₁	10.0	48.00	75.00	3600.00
	Z ₂	1.0	8.0	680.00	5440.00
	Z ₃	5.0	15.00	180.00	2700.00

Sources	ZnSO ₄ .7H ₂ O -	21% Zn
	Zn- EDTA -	12% Zn
	ZnSO ₄ . H ₂ O -	33% Zn

